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A REGIONAL AIR POLLUTION STUDY (RAPS) PRELIMINARY EMISSION INVENTORY

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This report presents an operational plan for providing emissions data for the Saint Louis Regional Air Pollution Study (RAPS). It also describes existing emission inventories for the Saint Louis area and reviews in detail emission models that have in the past been used to provide emissions data.

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I INTRODUCTION

This report presents an operational plan for providing emissions data for the Saint Louis Regional Air Pollution Study (RAPS). It also describes existing emission inventories for the Saint Louis area and reviews in detail emission models that have in the past been used to provide emissions data.

A. Saint Louis Regional Air Pollution Study (RAPS)

The Saint Louis Regional Air Pollution Study is the most ambitious study of its type ever attempted. Focused principally upon the verification and development of air quality models, it is also designed to develop a better understanding of atmospheric transformation processes and to provide a basis for studying various air pollution control strategies. Material advancements in the technology and methodology of air quality monitoring and other aspects of air pollution control, including particularly the improvement of emissions inventory procedures, are expected also.

Considerable attention has already been paid to measuring meteorological conditions and air quality in the test area, and a network of 25 automated data collection stations will be installed, stations which will continuously telemeter their readings to the data center. Data of this quality will be valuable to RAPS, particularly for diffusion modeling on an extended scale.

For the full realization of such purposes, however, especially for the modeling and prediction of air quality, it is essential to know the emissions from the air-polluting sources. Without effective assessment of such emissions to an appropriate degree of resolution in time and space, the experiments and studies of the RAPS program will be severely handicapped no matter how well other measurements are made or other factors assessed. To collect data on critical emissions for the multitude of different sources in an area the size of Saint Louis is a very tall order. It can only be met by an effort of considerable magnitude and cost for exceeding any previous undertakings of a similar nature. Indeed, it must be recognized that the requirement demands and warrants the application of detailed data collection procedures considerably different from those appropriate to a less rigorous determination of high resolution data and that many of the estimation or modeling techniques used hitherto cannot be used.

B. The Emission Inventory

To determine how to meet RAPS' needs for emission data, the problem was considered under five tasks. These logically follow each other sequentially, and they were addressed, at least initially, in that order. As the study proceeded, however, the interrelationship of the problems addressed under each task became ever more apparent, and, although the separate submission of the task reports in draft form served the useful purpose of checking and correcting progress, it was agreed that the results of the project were most useful when integrated as they are in this final report.

The tasks and their objectives were

- Task A. To ascertain the uses and users of emission data in the RAPS program (and elsewhere).
- Task B. To specify the content and nature of the emission inventory for RAPS.
- Task C. To specify the data formats and a data handling system needed for the inventory.
- Task D. To locate and assess existing sources of data suitable for incorporation in the RAPS inventory.
- Task E. To review the emission models available for developing emission data for studies of the type to be carried out in RAPS.

As noted, the full value of these tasks is only realized if they are allowed to interact, and a failure to recognize this until late in the project led to difficulties in formulating and presenting our conclusions.

In the final form, summarized below, the findings of the studies made under Tasks D and E have determined, to a certain degree, the content of Task B, which in turn reflects certain constraints and opportunities of the data handling system described in Task C.

C. Organization of the Report

The first part of this report, the Summary, is an overview of the project that summarizes the results. The second and largest part includes sections on the five separate tasks, each section reporting the appropriate detailed results. Appendix A is an assembly of data in printout form that pertains to Task D, and Appendix B is a lengthy summary of emission model reports.

II SUMMARY

A. Basic Concepts

The requirements of the RAPS program are wide ranging, diverse, and, in many cases, stipulate degrees of spatial and temporal resolution that have not hitherto been achieved. For the multiple purposes of the RAPS program, it is thus more appropriate to consider data on pollutant emissions in terms of a system of data resources than in terms of a single all-serving emission inventory. Alternatively, one can look upon an emission inventory for RAPS as being a multifaceted data source that comprises a number of elements, which are capable of providing needed information as required. In either case, we are led to a system in which varying criteria are applied to determining the nature and extent of the inventory content.

A major distinction can be drawn between the requirements of RAPS for high resolution data (in space and time), for such purposes as the verification and development of air quality models, and the more general needs of the program, such as, for example, investigations of economic, social, or political processes, or the investigation of control or abatement strategies not immediately served by the air quality modeling studies. This distinction leads immediately to a concept in which a special high resolution inventory (for pollutants of significance) is provided to the air quality modeling studies and other investigations (such as transportation processes or improved inventory methodology) where such high resolution data is appropriate. Those pollutants are SO_2, NO_x, CO, and hydrocarbons (HCs). For other pollutants, the high costs and difficulties of providing such high resolution emission data on a routine basis are not justified. For such other pollutants, we recommend that the National Emissions Data System (NEDS) Inventory be used.

When special information on emissions is required--for example, for extra precise high resolution data for limited "maximum effort" periods of model validation or for intensive transformation process investigations--we recommend that each such emission data collected be treated as a special case. This will avoid placing excessive requirements on the basic emission inventories and save cost and effort.

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It is convenient, therefore, in speaking of the RAPS emission inventory, to consider it primarily as the specially developed, high resolution data source concerned initially with SO_x, NO_x, CO, and HC. This inventory, as noted, must be flexible and capable of serving many purposes.

To ensure this, it is necessary to retain the basic or prime data from which it is built in its compilations in order to make revisions or extensions readily possible. Data should not be lumped in a form that applies to a single, or narrowly perceived, requirement.

The most satisfactory approach, wherever possible, is to provide files of emissions data for each pollutant in terms of direct statements of weight of pollutant emitted by each source or class of sources as a function of point or area location for every hour. Although this is a substantial undertaking, as described below, in most cases it can be accomplished to a useful level of precision within the RAPS program. This is mainly because the bulk of the emissions is a result of a limited number of sources. In a program of the scope of RAPS, it is possible to treat such sources individually and to use measured data providing direct or closely related information on emissions as the basis for hourly emission estimates. The frequency and quality of the measurements will be proportional to the magnitude of each source. This approach differs from that commonly used in developing emission data for purposes similar to the RAPS main objectives, which has perforce relied heavily upon emission modeling techniques to interpolate from gross annual data to provide information with high nominal temporal resolution. In the proposed RAPS inventory, such modeling techniques would only be applied to estimating hourly emissions from minor point sources or from area sources, although in certain of these cases it is recommended that the required precision demands the development of improved modeling methods for providing hourly data. In the case of mobile sources, however, where considerable progress has been made in assessing emissions with high spatial and temporal resolution, the current modeling approach is suitable for the RAPS inventory; the records of mobile sources to be incorporated in the inventory have a special form.

The term "emission modeling" sometimes leads to confusion, and it is necessary to clarify its significance. Strictly speaking, any computational manipulation of raw data can be described as modeling, for example, the combination of pollutant concentrations and flow rates to provide emission estimates. More often, modeling applies to the derivation or estimations of emissions from limited prime data, such as the estimation of emissions from residential space heating on an area basis (from a consideration of population density and daily temperature). In particular, the apportionment of emissions from any source or class of sources on, say, an hourly basis, from data such as gross annual tonnage of fuel burnt, is commonly performed by modeling using expressions (which can be more or less arbitrary) to describe the patterns of variability that occur by season, by day of the week, or by hour of the day.

In a more comprehensive sense, various emission models have been developed for specific purposes. These may consist of series of subelements integrated into a single system for deriving required emissions data. Such models are generally intended to provide emissions data in a specified form suitable for a particular use, deriving their estimates from relatively limited prime data (usually that relating to gross annual fuel consumption). A typical example is the Argonne Hourly SO_2 Model.[1] This model, described in detail in Section VII, provides hourly estimates of SO_2 and thermal emissions from power plants, industrial point sources, and one-square-mile areas of residential, commercial, and institutional sources. It derives such estimates from a range of input parameters based largely upon fuel consumption statistics as well as upon other factors such as temperature and time.

In considering such comprehensive emission models, it is important to emphasize their limitations for the purposes of RAPS. Adequate though they may be for the uses for which they were developed, they reflect the expediency and economy that was appropriate to such use. They seek to provide the best emissions estimates possible from available (i.e., minimal) data. They are not the best approach to developing emission inventories if better data can be specially acquired--as it can in the case of RAPS. Another aspect of emission models is the way that the specific output requirements determine the manner of developing the emission estimates from the prime data. This generally results in a lack of the flexibility needed to meet the multiple and varied demands of RAPS. The RAPS Emission Inventory should make emissions information available in such a manner that any desired selection of data may be extracted and presented in any desired form. This requirement is met by providing emission data in the form noted above, i.e., as direct statements of weight of pollutant emitted by each source, or class of sources as a function of location for every hour. In this approach, the emission modeling techniques, where used, are limited to the production of a common database, i.e., the general purpose high resolution emission inventory. The task of extracting emissions data for any purpose and of presenting it in any appropriate form then becomes a separate function.

It is recommended, therefore, that the RAPS inventory be developed upon the basis of specially collected data, rather than upon current emission models (with the exception of mobile source data). Further, it is recommended that the inventory provides flexibility and universality by being a simple compilation of all required data in the lowest common denominator form, i.e., hourly emissions by weight of each pollutant (SO_2, NO_x, HC, and CO).

For other pollutants, it is recommended that the National Emissions Data System (NEDS) be used.

B. Results of Specific Tasks

1. Task A

To determine the potential users and uses of the emission inventory for RAPS, a survey was made. Users range from the research groups directly involved in the RAPS program to city, county, and other planning organizations and air pollution control agencies in the area. Research programs other than RAPS were also considered. The principal uses of emissions data will be in the verification and development of transport and diffusion models and in studies of chemical transformation processes, the main interest of the RAPS program. Other uses will be in the analysis of economic, social, and political impact of air pollution and its control and abatement and in the development of such control and abatement strategies (particularly episode control). The RAPS emissions data could also be useful to programs such as the Community Health and Environmental Surveillance System (CHESS) or research studies such as METROMEX (a joint investigation of meteorological effects of air pollution) or other locally based investigations requiring detailed knowledge of pollutant emissions.

Two factors emerge from this survey. First, the requirements for these purposes are multiple and diverse, covering a wide variety of pollutants and very different degrees of temporal and spatial resolution. Second, the needs of the air quality modelers are the most demanding, and they dominate the requirements for high resolution data in space and time.

The needs for emissions data in the RAPS program can, thus, best be met routinely by

- Relying on NEDS for data on the broad range of pollutants for which high resolution information is not essential.
- Developing a special RAPS Emission Inventory capable of providing the high resolution data needed by the modelers and of serving other purposes.

For special purposes, such as particular experiments to investigate chemical transformation processes or studies of the dispersion of specific pollutants for which the above mentioned inventories are inadequate, appropriate special data collections should be made to determine emissions on an experimental basis. (Such data may be collected, processed, and stored within the RAPS Emission Inventory data handling system, but are not an integral part of this inventory.)

The specification of various air-quality model input requirements that act as common denominators thus determines what is required of the RAPS Emission Inventory. Specifically, the requirements are

- Pollutants: SO_2, CO, NO_x, hydrocarbons (by types), and particulates.
- Resolution: Temporal, hourly, for each hour; spatial, 0.01 km point sources, 1 km^2 grid squares [area sources using Universal Transverse Mercator (UTM) coordinates in each case].
- Area covered: The Saint Louis Air Quality Control Region (AQCR).
- Period covered: Continuous hour by hour throughout the years of full RAPS operations.
- Units: Emissions by metric weight; distance in kilometers, in UTM coordinates.
- Output format: Variable, but in FORTRAN compatible form.
- Other information: Data on sources (e.g., stack height, exit temperature, velocity) where appropriate; data for mobile sources, traffic flow data, and aircraft movements as required for use in appropriate emission models.

2. Task B

In this task (specification of the content of the RAPS Emission Inventory) an extensive analysis was made of the problems of developing emission data with the necessary spatial and temporal resolution and accuracy to meet the requirements of RAPS.

After an initial review of the basic form the inventory system should take to meet the multiple purposes of RAPS, we discussed each aspect of such a system in detail.

Because of the need for precision in estimating the emission and the requirements for spatial and temporal resolution, a quantitative basis can only be provided by analyses made for specific air quality or dispersion models (as discussed in Section VII). The emission inventory can potentially provide the most complete data input to such models, depending upon the cost and effort applied, although even in the most careful direct assessments of emissions at individual sites, uncertainties of ±10 percent must be expected. We described the pollutants of interest, distinguishing between the reactive gases, nonreactive gases, and particulates. The role of the emission inventory of such pollutants is discussed in the context of RAPS. While data can fairly readily be obtained for the key gaseous pollutants, particulate emissions are extremely difficult to monitor. Existing data on such emissions are often inaccurate and give no information on the size distribution of the particles, which is so important in the modeling context. In the circumstances, it is proposed that particulates not be included in the high resolution inventory on an hourly basis, and that the needs of RAPS for particulate data for dispersion model studies or research on transformation processes be dealt with on a special experimental or project basis--including, specifically, the use of tracer techniques.

The study team described and analyzed sources categorized according to identity, function, and pollutant emitted. Each category is discussed in detail, necessary for the data collection procedures to be recommended later.

The importance of emission and data conversion factors is then noted. Such factors are critical to any inventory and especially to an inventory of the type needed for RAPS. The economics of the problem, however, are such that, while it would be desirable to test every sizeable source in the inventory on an individual basis, wherever reasonable confidence can be placed in standard emission factors, these should be used in practice. Finally, the physical characteristics of the sources needed for the inventory are noted, and recommendations are made regarding the metric units to be used.

The second part of Task B was to specify the RAPS Emission Inventory system outlined below.

While NEDS is proposed as a source of information on annual or long-term emissions from a broad range of pollutants, it is recommended that a special, high-resolution RAPS Emission Inventory be developed to provide hourly data emissions of SO_2, CO, NO_x, and HC in the form of direct statements of weight of pollutant emitted in kilograms each hour from each point or line source or area element for the Saint Louis AQCR. Locational data will be provided in UTM coordinates with a resolution of at least 0.1 km for point sources. Mobile sources will be specified in terms of traffic links (with a resolution of approximately 0.2 km) for major routes and in areas for secondary routes. Both for stationary and mobile sources, the area elements will reflect either the spatial resolution of the basic data from which the emissions are estimated (e.g., housing developments) or one kilometer grid squares, whichever is the smaller. Information on the physical characteristics of point sources and the prime data used in compiling the inventory would also be provided. It is not considered practicable to develop comparable data for particulates.

For initial planning purposes we propose that only point sources emitting over 100 tons per year of each pollutant be considered individually. The estimation of emissions from such sources will be accomplished in classes according to the magnitude of each source. In general, we recommend that emission data be based upon direct monitoring of emissions for the largest sources. For other major sources, direct monitoring of hourly fuel consumption, operating, or process data should be used as the basis for estimating emissions. For smaller point sources, we propose that emissions be estimated on the basis of generalized patterns of temporal variation of emission as a function of source type applied to the best available data on fuel consumption, operating, or process data (per shift, daily, or weekly). This approach approximates current practice in which annual totals of such data are used as a basis for modeling. For area sources, we recommend the use of modifications and adaptions of already available emission models. Similarly, for a first approach to assessing mobile source emissions, we recommend the use of available models. Improved mobile source models should be employed, as they become available, to provide higher quality data. A simple new model should be developed to estimate natural emissions of nonmethane hydrocarbons on summer days. In all cases, we propose that special testing efforts be carried out to ensure that the emission and data conversion factors used to derive the emission estimates are as reliable as possible, and have regard for the high temporal resolution required. Standard emission factors should only be employed if a review of the source on a case-by-case basis indicates that such a factor may be used with confidence.

The concluding portion of Task B is a description of methodology and detailed procedures for developing the inventory in the form proposed. Point sources using the NEDS data are classified according to size to facilitate the description of how emission data would be derived in four broad groups according to the basic records used to estimate emissions--Group I, continuous emissions monitoring records; Group II, continuous records of fuel consumption, operating, or process data; Group III, short term, periodic records of fuel consumption, operating, or process data (per shift, daily, or weekly); Group IV, long-term (semiannual or annual) records or estimates of fuel consumption, operating, or process data. Within Groups II and III, a further distinction would be made between sources for which separate conversion or emission factors are established and those for which representative factors will be established. Data from Groups I, II, and III will be collected on an ongoing basis.

In principle, it would obviously be desirable to deal with all sources under Group I. In practice, sources should be treated in the highest ranking group possible within limits of cost and difficulty. Some 95 percent of the SO_2 emissions and 70 percent of the NO_x emissions can be derived from direct data (Groups I, II, and III) on the basis of routine data inputs from 101 sources with a high confidence based upon the testing of 65 individual sources. Similarly, in the case of CO sources, over 90 percent of the emissions can be estimated on an hourly basis by the treatment of direct data from only six sources. On the other hand, it would be necessary to obtain data from and test some ten or more sources to achieve hourly estimates from direct data for only 50 percent of the HC emissions. The proposed approach, however, is intended to provide considerable flexibility, so that optimum results can be achieved within budgetary and other limitations. Thus, the number of sources to be treated on an individual basis and the numbers of tests to be made should be decided upon the basis of an initial survey on a case-by-case basis.

In the case of area sources, the shortcomings of existing emission models require that special efforts be made to improve and verify these, for, although such sources contribute only a small proportion of the total burden, their local effect is significant. Similarly, in the case of mobile sources, while a simple form of existing models will suffice initially (with improved traffic data inputs), the products of more sophisticated models should be used as they become available. Finally, it is noted that a method for estimating emissions of nonmethane hydrocarbons from natural sources on summer days is needed.

Task B includes a tentative schedule aimed at providing initial data on SO_2 and NO_x by the first quarter of the second year of full activities, complete data by the third quarter of that year; effective initial data on CO and HC would become available by the end of the second year, and complete data would be available by the third quarter of the second year.

3. Task C

Task C is the specification of a system for handling, storing, and processing the relevant data. Specification is based upon certain assumptions regarding the nature and capability of the data management system that will be available as part of the RAPS overall data handling system. These assumptions either indicate facilities that are normally provided by such a system or could be readily provided by appropriate adaptation or additional programming of a conventional type.

In order to specify the data formats and structures, it is necessary to determine how the inventory files will be used as a system for source data preparation and entry, for processing data through emission models, and finally, for production of the data files for the various user activities. The system is designed to minimize manual transformations of the raw data to the form in which it is entered into the computer. Input data are thus based upon the sources, and all pertinent data (e.g., pollutants, fuels, consumption) are entered in direct form as reported. Rather than using integer codes such as the SAROAD manual, we propose the use of direct, mnemonic identifiers. We also specify the use of a hierarchical, list type structure to enter such data and similar necessary information. This leads to data structures that comprise extendable data items within an appropriate data reference system allowing maximum flexibility both to accommodate disparate types of data and to allow ready extension to cope with new or additional data forms that might need to be added after the establishment of basic lists or thesauri.

The master inventory file will consist of data items, each of which describes a source or a set of identical sources. Each item will include source identification data, source operating parameters, the set of primary measurements from which emissions will be computed, and the set of computed hourly emission values for each pertinent pollutant. This inventory file is designed as the core of the whole inventory system. It will be supported and maintained by a general-purpose data management system and by such special-purpose programs as may be required for verification, emission computations, and production of data files properly formatted for use as input to air quality models.

4. Task D

Task D, the review of the existing emission data sources in the Saint Louis area, has been disappointing. Despite the fact that Saint Louis has been the site of a number of advanced air quality studies and has active and well-organized local air pollution control agencies, the available emissions inventory data is quite inadequate for the purposes of RAPS. Although the emissions data that have been collected in the area place it in the forefront of urban areas in the availability of such information and the existing data fairly well meets (or met) the requirements for which it was collected, it falls far short of the new and highly demanding requirements of RAPS. Specifically, the data do not provide for hourly resolution.

The five major inventories considered are the IPP (1968), IBM (1970), DAQED (1971), NATO (1971), and NEDS (1973) inventories. Of these, the first four are now essentially of historical interest only. The NEDS inventory contains the best current estimates and constitutes a valuable source of general data for the broad requirements of RAPS. For the principal purposes of RAPS (model verification and development and study of atmospheric transformation processes), NEDS will serve as a basis for developing the high-resolution RAPS Emission Inventory necessary to meet the requirements of the modelers and others.

Thus, NEDS provides good information on point sources that is of use in planning and implementing the RAPS inventory. In addition, it provides basic inputs on area and mobile sources for the advanced purposes of that inventory.

5. Task E

In this task, 28 existing emission models relevant to the objectives of RAPS were reviewed in detail. In Appendix B, complete information--the author's abstract, our summary of the significant features of the models, and the form and availability of documentation--on the models is provided.

The models are considered in terms of emissions type, source mobility and configuration, and the degree of experimental verification that has been carried out. It is significant, however, that only three of the 28 models reviewed have undergone independent experimental evaluation of the emission estimates.

The models considered range from fairly limited procedures for specifying the emissions of a single pollutant from a narrow range of sources to much more ambitious attempts to specify a number of pollutants emitted by a comprehensive range of sources. In the latter case the model is, in fact, a collection of submodels.

A common feature is the way in which the particular objectives of each model determine the manner of developing and presenting the emissions data from the prime data. This results from the difficulties of achieving time resolved emission data of relatively high spatial resolution from the limited information available. For predictive and modeling procedures, the emphasis has also naturally been upon deriving the wanted inputs in the most economical and expeditious manner possible, rather than upon developing inventories of general applicability. Again, the basic or prime information (e.g., annual fuel consumption) is all too often very gross, and much reliance is placed upon extensive interpolation procedures. Since these modeling procedures are clearly of limited precision for use in the context of RAPS requirements and since, in the absence of extensive verification, confidence in their use must be guarded, it was not possible to recommend the use of such models unreservedly for the RAPS program. Certain models appear to have potential utility for the purposes of RAPS depending upon the degree to which interpolation procedures will be needed (as distinct from the preferable procedure of deriving emissions directly from time resolved related data). These models are noted below.

In addition to the review of existing models, a brief analysis is also made of the nature of and need for verification procedures. In particular, a procedure is set out for evaluating the validity of mobile source models by combining specially collected experimental data on traffic volume with basic statistical data.

Another point addressed in detail is the degree of resolution required for the specification of location of point sources. The interplay of source strength, stack height, lateral and longitudinal receptor position, and atmospheric stability makes the definition of locational precision complicated and complex. Accordingly, a new methodology is developed to enable the varying interrelated factors to be considered for any given circumstances, enabling the effects of positional error to be assessed for any downwind distance or distance interval, and providing a recommended spatial resolution for each source specification based upon stack height and emission rate. Finally, the role of natural mechanisms in adding significantly to the man-made pollutant burden of the Saint Louis region is considered.

The specific conclusions that result from the studies carried out under Task E are listed here.

- No existing models adequately meet all the requirements of RAPS.
- To provide emissions data with the necessary high resolution in space and time, it is recommended that
    - Direct information of emissions or of factors determining emissions be acquired to the extent possible.
    - Where this is not possible (e.g., for small point sources and area sources) the most suitable of the existing models should be used in adapted and improved form.

- Specifically, for stationary sources
    - Direct data from emissions monitoring should be used wherever available (probably only for the largest sources, such as power stations).
    - Information on hourly fuel consumption rates, process operations, and so forth should be obtained and used to derive emissions for other large sources.
    - Modeling procedures for small point sources and area sources, based upon the models noted below, should be used, but, with refinement of the input data wherever possible.
    - Recommended models are the Argonne model[2] (for hourly SO_2 from distributed residential, commercial, and institutional sources; and hourly SO_2 and heat from major point sources) and the Systems Applications, Inc. (SAI) model[1,3] (for hourly NO_x and HC from stationary point and area sources).
    - For automotive mobile sources, we recommend that an average route speed model be used with a link or line source geometry supplemented with measured data of traffic flow from fixed sensors on high volume freeways and on selected arterials.
    - The recommended models are the SAI model[1,3] (for hourly CO, NO_x and HC with modified inputs derived from Stanford Research Institute's model[4] for spatial and temporal distribution of vehicle number and speed on a link basis for primary traffic and area basis for secondary traffic).
    - For other mobile sources, the recommended models are the Geomet model[5] (for diurnal emissions from river vessels and railroads) and the Northern Research and Engineering model[6] as revised by Geomet (in preparation, for aircraft emissions).
    - For both stationary and mobile sources, the Ontario Department of the Environment 1971 Model for Toronto should be referred to for overall guidance and planning methodology.
- For microscale studies under the RAPS program, the basic inventory will need to be supplemented with special emission inputs. These should be obtained on an experimental or project basis (e.g., the acquisition of detailed data

from small stationary sources or for mobile sources, continuous and detailed monitoring of vehicle behavior in a given area with the application of a multimodal emission model to forecast emissions).

- In view of the limitations of existing mobile emission source models and the impossibility of resorting to direct information, it is recommended that special steps be taken to improve and verify such mobile emission models. Specifically,
  - An experimental evaluation should be made of mobile emissions models to refine the specification of process input parameters and the accuracy of postulated input-output relationships.
  - Parameterization of inputs for mobile emissions (statistical database plus continuous measurement of vehicle volume, speed, and mix on key links to generate a dynamic link-by-link inventory) should be verified on a selective basis via aerial photography and/or side-looking aerial radar.
  - Parameterization of outputs from mobile sources should be evaluated in various models to verify representation of time-averaged emissions on a per-link basis taking into account types of link and the impacts of deterioration, mix, road grade, drag, and so forth.

- Of the pollutant emissions (CO, NO_x, SO_2, H_2S, nonmethane HC, and particulates) from natural phenomena in the Saint Louis area, nonmethane hydrocarbons may contribute a significant background during summer daylight hours and should be included in the RAPS emission inventory. Suitable procedures to estimate these should be developed early in the RAPS program.

- In the context of the RAPS program, the accuracy of point source locations is best considered in terms of the effect of errors throughout the study area. Accordingly, we propose that a measure of error in source location be defined as the integral value of the error over both the lateral (crosswind) and longitudinal (downwind) directions.

C. Recommendations

The following recommendations provide an outline of an operational plan to derive the RAPS Emission Inventory.

- An initial survey should be made of point sources emitting over 100 tons per year of SO_2, NO_x, CO, or HC. The survey should be based upon the information of the NEDS inventory, and as many as possible of the sources should be inspected. An initial assessment, based upon the nature and quality of the records available, should be made on how each source should be treated by group (according to the data collection procedure).

- With regard for budget and the results of the survey, detailed plans should be made as to the number of sources to be treated in each group, especially the number of individual source tests to be made.

- Meanwhile, the proposed data handling system should be developed and coordinated with the specific data management system actually procured for the RAPS project.

- As soon as possible, effort should be applied to the development and refinement of emission modeling procedures to meet the needs of the RAPS inventory. Specifically, improved techniques of handling shorter term input data for both point source and area sources should be applied to the Argonne model and the SAI model. For mobile sources, similar improvements should be made on the basis of the SAI model with modified inputs derived from the SRI model. A model must be developed to estimate summer day emissions of nonmethane hydrocarbons from natural sources.

- Following the detailed plan developed from the initial survey, an intensive program of source testing should be undertaken to develop a reliable basis of emission factors or conversion factors to relate the routinely collected input data to the emissions of specified pollutant on an hourly basis.

- Arrangements must be made for the routine periodic collection of input data from the sources to be treated on that basis or additional data for modeling purposes not acquired in the source of the initial survey. Arrangements should also be made to install any necessary monitoring equipment provided under the RAPS program for point sources or measuring traffic flow on selected high volume freeways or arterials.

- Finally, the system should be operated on a routine basis following the sequence noted in Task B to provide data first on SO_2 and NO_x and later on CO and HC.

- In support of the inventory development effort, the following inputs should be sought from other elements of RAPS as early as possible:

  - Tests of specific air quality or dispersion models should be made to ascertain sensitivity to the precision and resolution of emissions data in the Saint Louis area (using NEDS data as a basis).

  - The vicinity of air monitoring stations should be surveyed and any significant point sources within a radius of say one kilometer of each station should be identified so that consideration can be given to treating them on an individual basis even though they do not emit over 100 tons of pollutants per year.

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III TASK A: DEFINITION OF POTENTIAL USERS AND USES

A. General

An emission inventory is a fundamental part of any air pollution study. The Regional Air Pollution Study (RAPS) in Saint Louis is expected to be unique in scope and depth. Consequently, the emission inventory contemplated for this study needs to be far more detailed and accurate than those currently available.

The actual scope, content, and format of the RAPS inventory is determined by its proposed use, and, in order to ensure that the inventory will correspond as closely as possible to the demands placed on it by future users, a survey was made to determine the characteristics desired by potential users both within EPA and elsewhere. Primary consideration was given to RAPS requirements. To complete the picture, the needs of other potential users were then considered.

B. Summary

Although an emission inventory is a key information base for all air pollution studies and control strategies, it is of direct use to RAPS investigators concerned with the relationship between ambient concentrations of pollutants and their source, that is, the modelers. Other groups directly concerned with emission inventories are (1) the regulatory agencies charged with the achievement and maintenance of the National Air Standards (this group has the responsibility and authority to collect and store emission data) and (2) other workers in the field concerned with transportation problems, health effects, plant damage, and the like (these groups are primarily concerned with ambient concentrations of pollutants of interest).

The requirements of these users are quite different. The modelers are concerned primarily with those pollutants for which air quality standards have been promulgated, that is, sulfur dioxide, carbon monoxide, hydrocarbons, nitrogen dioxide, and suspended particulates. The information they require is very detailed (accurate location of the sources, detailed information on emissions as a function of time, and precise estimates of quantities emitted are all essential). The period for which such high resolution data is needed will vary considerably. In many cases, model verifications will be limited to relatively short periods, of, say, 48 to 72 hours, selected for representative meteorological conditions. Since such periods may not be readily determinable until a later time, when the best combination of circumstances is determined, post facto, it is necessary to collect appropriate emissions data on a continuing basis, parallel with the even more comprehensive continuous measurements of air quality and meteorological factors.

The requirements of the people working with health effects or plant damage, on the other hand, are quite different. The range of pollutants of interest is very broad, including not only compounds of known toxic effects such as mercury or cadmium but also an almost infinite variety of compounds suspected of having an effect on plants or people. For these purposes, detailed time resolution of emission is seldom required (except in cases of accidents or unusual meteorological events) since most effects are cumulative over long periods of time. Therefore, long-time historical records on many substances are of main importance in determining causative relationships of air pollution to health or vegetation effects.

State and local regulatory agencies are in a sense caught between these two requirements. They have to maintain inventories adequate for the enforcement of legal standards, and they would like to have records of emissions that are potentially hazardous.

As RAPS may eventually include a number of investigations that currently are not well defined, it is essential to include in the inventory design the flexibility required for the addition of other pollutants. For the moment, however, the primary users of the RAPS emission inventory are the modelers, and it is their requirements that have to be met. In the following section the details of these requirements are delineated. Table 1 summarizes the requirements.

C. RAPS Requirements

The Saint Louis emission inventory is of prime concern to the RAPS research groups engaged in the development, evaluation, and refinement of air pollution models. Several types of models are currently under consideration or active study as part of one RAPS study plan;[7] in this plan, the four basic model types are emission, atmospheric structure, transformation, and removal process models. Also being considered are existing models that encompass one or more of the basic models, such as some models that treat the generation and dispersion of pollutants from certain transportation sources.

Table 1

EMISSION INVENTORY REQUIREMENTS

Requirements / Uses or Users	Type of Source			Spatial Resolution												Average Time Resolution					
				Point		Area				Line										
										Endpoints										
	Point	Area	Line	0.1 km	0.01 km	$<1\ km^2$	$1\ km^2$	$>1\ km^2$	Other	UTM	Intersections	Width (meters)	Centerstrip Width (meters)	Type	Year	Season	Month	Week	Day	Hour
RAPS Models																				
Atmospheric structure	x	x			x		x													x
Transformation processes	x	x	x		x		x			x										x
Vehicular sources			x							x		x	x	x						x
Airport model	x		x	Each plane							Runway-taxiway-gate						Each flight			
Regulatory Agency																				
City of Saint Louis APC	x	x	x	x		x					x				x	x				
Saint Louis County APC	x	x	x	x		x					x				x	x				
Illinois State APC	x	x	x	x		x									x	x			x	
Missouri Air Control Commission	x	x	x	x		x									x	x			x	
Research																				
Metromex	x			x																x
CHESS									School districts						x					x
Plant damage studies	x			x													x	x		

Requirements / Uses or Users	Units		Pollutants																			
	Metric	Engineering	SO_2	CO	NO_x	Oxidant	O_3	PAN	Hydrocarbons	Hydrocarbons by Groups	Hydrocarbons by Compounds	Particulates	Water Vapor	Heat	Fluorides	Sulfates	Asbestos	Trace Metals	BaP	PCB	Pollen	Hazardous Materials
RAPS Models																						
Atmospheric structure	x		x	x								x	x	x								
Transformation processes	x		x	x	x	x					x	x										
Vehicular sources	x			x	x					x		x										
Airport model	x			x	x				x			x										
Regulatory Agency																						
City of Saint Louis APC		x	x	(x)	x				(x)			x										
Saint Louis County APC		x	x	x	x				x			x										
Illinois State APC		x	x	x	x				x			x										
Missouri Air Control Commission		x	x	x	x				x			x										
Research																						
Metromex	x											x										
CHESS	x		x	x	x	x	x				x	x				x	x	x	x	x	x	x
Plant damage studies	x		x		x		x	x							x							

Upon examination of the four basic models, it can be seen that only the emission model is self-contained. The others exhibit various degrees of interdependence. For example, a model of boundary layer structure will need to account for the meteorological effects that result from emissions of, say, heat and water vapor. Similarly, transformation models must consider both emissions and atmospheric structure models, while removal process models consider all three models. Thus, in assessing the requirements of the various specific models, we need to recognize that, while the primary emphasis of the particular model may be one thing, it is quite likely and indeed probable that many of its input requirements derive from the structure of the other model components.

Up to now little effort has been devoted to the development of comprehensive or nonspecialized emission models. In fact, the development of a framework for a RAPS emission model program is an objective of this study. In the absence of an established emission model that the emission inventory would serve, we have surveyed the various model requirements for emission inputs so as to specify criteria and objectives for such an inventory. These models and their requirements are discussed below.

1. Atmospheric Structure Models

Atmospheric structure models describing transport and diffusion within the planetary layer on a regional scale (≤30 km) are being developed at the Model Development Branch, Meteorology Laboratory, NERC, Research Triangle Park, North Carolina. The specific requirements related to emissions are shown in Table 2. The model is currently under development, and, hence, these requirements reflect our best judgment based on available information. Three additional models used at the Meteorology Laboratory of NERC are

- PTMAX, an interactive program that performs an analysis of the maximum, short-term concentration from a point source as a function of stability and wind speed.
- PTDIS, an interactive program that computes short-term concentrations downwind from a point source at distances specified by the user.
- PTMTP, an interactive program that computes, at multiple receptors, short-term concentrations resulting from multiple point sources.

Table 2

EMISSION INVENTORY INPUT REQUIREMENTS FOR ATMOSPHERIC STRUCTURE (WATPIC) MODEL

Content of inventory	SO_2, CO, particulates, heat, water vapor
Time resolution	1 hour
Spatial resolution	Point sources on UTM grid (±0.01 km) Area sources on variable grid from 1 km^2
Preferred medium	Tape
Units	Grams/second, watts
Source descriptors	Stack height (meters), exit velocity (meters/second), temperature (°K), stack diameter (meters)
Temporal variations	Diurnal, daily, seasonal
Level of confidence	Depends on source of data (stack sampling, questionnaires)

We believe that the emission inventory input requirements of these models are met by the specifications in Table 2. However, when the manuals for these models become available, we will review those requirements.

2. Transformation Processes Models

Many materials emitted into the atmosphere undergo not only physical dispersion but chemical changes as well. We need to know the whole life history of a pollutant, from emission through chemical and physical transformation to eventual removal, before accurately predicting the relationship of emission to air quality.

At present, the fate of six major pollutants is under investigation by modelers at Research Triangle Park and outside contractors under the guidance of the Chemistry and Physics Laboratory. The pollutants are sulfur oxides, nitrogen oxides, hydrocarbons, oxidant, carbon monoxide, and particulates. The photochemical transformations have received the most attention so far. The emission inventory inputs into this model are listed in Table 3.

Table 3

EMISSION INVENTORY INPUT REQUIREMENTS
FOR THE TRANSFORMATION PROCESSES* MODEL

Content of inventory	SO_2, NO_x, O_3, CO, HC, particulates (NO_x by compounds; HC by categories, e.g., paraffins, olefins, aromatics)
Time resolution	1 hour
Spatial resolution	Point sources on UTM grid. Line sources (end points) in UTM coordinates. Area sources on variable-size grid from 1 km^2. Eulerian models utilize a fixed rectilinear grid, while Lagrangian models may require a flexible grid aligned along a given wind trajectory.
Preferred medium	Tape
Units	Grams, meters, seconds
Source descriptors	See Table 1
Temporal variations	Diurnal, daily, seasonal
Level of confidence	Depends on source data

*Principal candidate-model EPA contractors:

1. Systems Applications, Inc.
   Beverly Hills, California 90202
2. General Research Corporation
   Santa Barbara, California 93105
3. Pacific Environmental Services, Inc.
   Santa Monica, California 90403
4. Systems, Science & Software, Inc.
   La Jolla, California 92037

3. Mobile Sources

a. Surface Vehicles

Emissions from mobile sources such as automobiles, trucks, railroads, and vessels constitute an important segment of urban pollution. They account for virtually all of the carbon monoxide, the bulk of hydrocarbons, and a significant share of nitrogen oxides.

Since emissions from these sources are a function of the speed, number, and type of vehicles and the traffic patterns for given highway segments, they are best represented as line sources for heavily traveled streets. Lightly traveled areas can be considered area sources.

Emission inventory inputs into transportation-related models will require items indicated in Table 4. Emission requirements of models that treat vehicular sources have been limited to the requirements of mesoscale transportation modes. Microscale models--those treating near-source effects--may have more stringent emission requirements both in quantity, types, and precision of the data. Consequently, these

Table 4

EMISSION INVENTORY INPUT REQUIREMENTS
FOR VEHICULAR SOURCES MODEL

Content of inventory	CO, hydrocarbons (by types such as olefins, paraffins, aromatics), NO_x, particulates
Time resolution	1 hour
Spatial resolution	Street segments. Endpoints (in UTM coordinates), width (meters), center strip width (meters). Type of roadway at grade, elevated, cut section, street canyon. 1 km^2 (minimum) blocks for area sources.
Preferred medium	Tape
Units	Grams/second, meter
Source descriptors	Mean speed (meter/second), traffic volume by mix
Temporal variations	Diurnal, daily, seasonal
Level of confidence	Depends on source data (sampling, traffic counts, simulated traffic patterns, and the like)

types of highly specialized requirements are not within the scope of the basic inventory and will need to be obtained as a special task in conjunction with the particular microscale model experiments and evaluations.

b. Aircraft and Airports

Models dealing with pollutant emissions from planes on the ground level and above airports are also being developed. These are essentially microscale models dealing with the movement of individual aircraft during landings, taxiing, and takeoff. The degree of detail of emission data required for such a model (Table 5) is probably outside the scope of a regional inventory.

This work is coordinated by the Model Applications Branch of the Meteorology Laboratory, NERC, Research Triangle Park.

Table 5

EMISSION INVENTORY INPUT REQUIREMENTS
FOR MOBILE SOURCES (AIRPORTS) MODEL

Content of inventory	CO, hydrocarbons, NO_x, particulates
Time resolution	Every flight: taxiing time, takeoff and landing
Spatial resolution	Each runway, taxiway, gate, direction of takeoff
Preferred medium	Tape
Units	Grams/second, meter
Source descriptors	Type of plane
Temporal variations	
Level of confidence	

c. Railroads and Vessels

The contribution of railroads and vessels to the air pollution burden of the Saint Louis area is under investigation by the Transportation Center, Department of Transportation, Cambridge, Massachusetts.

The Center is conducting a study that will include a survey, an experimental program to obtain emission data and some dispersion modeling studies. In the course of this work, the Center will be both a user of and a contributor to the RAPS emission inventory.

The main pollutants of concern are SO_2 and particulates.

4. Other Studies

a. Particulate Emissions

Visibility loss caused by suspended fine particles is one of the most obvious manifestations of air pollution. Particles also may be involved in gas phase reactions and provide one of the mechanisms for the removal of nitrogen and sulfur oxides. Thus, the formation and removal of fine particles is part of our understanding of atmospheric reactions and will ultimately have to be accounted for in models describing such reactions.

Particles also play an important role in health studies, since those fine enough to remain suspended for indefinite periods (2 to 3 microns) are breathed in and can deposit in the lungs. Thus, there is a particular interest in this fraction of particulate emissions.

Studies are under way under the auspices of the Chemistry and Physics Laboratory, NERC-RTP, in the Saint Louis area to measure particle size distribution and their chemical analysis. Data on the emission of particles are needed, including data on size distribution of major sources. At the very least, data on the coarse (greater than 3μ) and fine (less than 3μ) fractions should be obtained.

b. Various Analyses

In addition to the modeling studies dealing with the physical characteristics of air pollution, such as emissions, air movement, or ambient concentrations of pollutants, the RAPS data are expected to be used for a number of studies and analyses dealing with the social, economic, and political impacts of air pollution and its control. Most of these studies will be based on long-term averages, and they do not require the fine resolution the RAPS inventory will provide. Still, they will profit from the increased accuracy of the new inventory.

The development of an inventory of the scope and detail of the Saint Louis study is in itself no mean achievement. On the basis of the experience gained in this study, guidelines for improved emission inventory procedures will no doubt be developed.

D. State and Local Control Agencies

The Metropolitan Saint Louis Interstate Air Quality Control Region comprises two states--Missouri and Illinois--and 12 counties. Five counties are in Missouri (Saint Louis City, Saint Louis, Saint Charles, Jefferson, and Franklin); seven are in Illinois (Bond, Clinton, Madison, Randolph, Saint Clair, and Washington). The Missouri counties are under the jurisdiction of the EPA Region VII office at Kansas City, Missouri. The Illinois counties are the responsibility of the EPA Region V office at Chicago, Illinois. Saint Louis City and Saint Louis County have separate air pollution control offices; the other Missouri counties are administered directly by the Missouri Air Conservation Commission at Jefferson City. The seven Illinois counties are under the jurisdiction of the Illinois Environmental Protection Agency. The area is shown in Figure 1. The crosshatched areas are those covered more completely by monitoring stations.

The ultimate purpose of the state and local control agencies is to achieve and maintain the air quality that corresponds to at least the national primary and secondary air standards, although states may establish more stringent standards. Thus, control agencies are concerned not only with pollution episodes (emergency conditions), but also with long-term pollution control programs aimed at a gradual reduction of air pollution levels and with community growth planning as it relates to added pollution. Ultimately, they are responsible for the effect of pollution on the health of the community, its vegetation, and perhaps even weather modifications.

1. City of Saint Louis

The Air Pollution Control Office, Department of Public Safety, City of Saint Louis, has a source evaluation section in charge of the emission inventory; it has identified some 16,000 point sources, but reliable data are available primarily for the large sources. The section's primary mission is enforcement rather than data collection.

The emission inventory is in the form of reports gathered by inspectors. The data were not computerized. See Table 6.

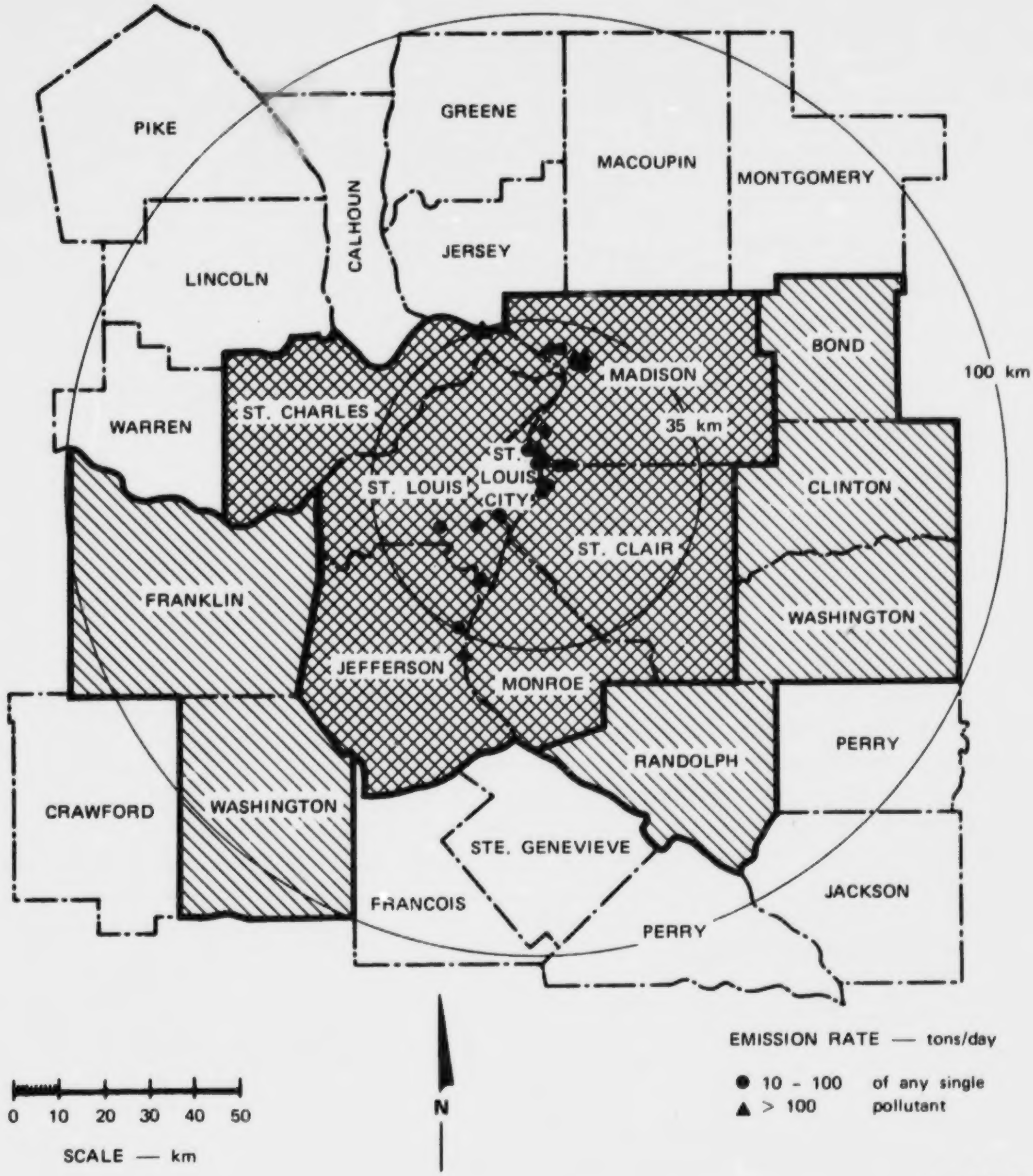

PIKE
GREENE
MACOUPIN
MONTGOMERY
CALHOUN
JERSEY
LINCOLN
BOND
MADISON
100 km
WARREN
ST. CHARLES
35 km
ST. LOUIS CITY
ST. LOUIS
CLINTON
ST. CLAIR
FRANKLIN
WASHINGTON
JEFFERSON
MONROE
PERRY
RANDOLPH
CRAWFORD
WASHINGTON
STE. GENEVIEVE
JACKSON
FRANCOIS
PERRY
EMISSION RATE — tons/day
● 10 - 100 of any single
▲ > 100 pollutant
0 10 20 30 40 50
SCALE — km
N
SA-1365-33

FIGURE 1 METROPOLITAN SAINT LOUIS INTERSTATE AIR QUALITY CONTROL REGION

Table 6

EMISSION INVENTORY INPUT REQUIREMENTS
OF THE AIR POLLUTION CONTROL OFFICE,
CITY OF SAINT LOUIS

Content of inventory	SO_2 (HC, CO), NO_x, particulates
Time resolution	Yearly average output
Spatial resolution	Point sources, UTM coordinates
Preferred medium	Reports
Units	Engineering
Source descriptors	Stack height, exit velocity, temperature
Temporal variations	
Level of confidence	Inspectors' reports

2. Saint Louis County

The Air Pollution Control Division, Saint Louis County Health Department, like its Saint Louis City counterpart, is primarily an enforcement agency. It has identified the major pollution sources (about five that are emitting more than 100 tons per day, about 20 with emissions in excess of 25 tons per day). Some modeling of sulfur dioxide concentrations has been done, and some CO modeling is contemplated. The inventory (Table 7) is based on inspectors' reports. The control of additional pollution resulting from the growth of the area through proper land use is under consideration.

3. Missouri Air Conservation Commission, Jefferson City, Missouri

This agency has responsibility for the air quality of the state of Missouri. It operates through county or local air pollution control boards where such agencies exist, and it operates directly in other areas. Its function is to promulgate and enforce air pollution standards for the state of Missouri.

Table 7

EMISSION INVENTORY INPUT REQUIREMENTS
OF THE AIR POLLUTION CONTROL DIVISION,
SAINT LOUIS COUNTY HEALTH DEPARTMENT

Content of inventory	SO_2, NO_x, CO, HC, particulates
Time resolution	Yearly averages
Spatial resolution	Point sources on UTM coordinates
Preferred medium	Printout or tape
Units	Engineering
Source descriptors	Stack height, exit velocity, temperature
Temporal variations	None
Level of confidence	Major sources have been updated and some stack sampling is performed every six months

At present, the commission maintains data on particulates, SO_2, NO_x, total hydrocarbons, and CO. The data are based on an original survey carried out in 1968 (for particulates and SO_2 only), which has been updated in 1970 by IBM to include the other three pollutants. It was further updated in 1972 by Radian, Inc., and is now in National Emissions Data System (NEDS) format.

Emission input requirements are similar to those shown in Table 7 for Saint Louis County.

4. Illinois Environmental Protection Agency, Division of Air Pollution Control, Springfield, Illinois

The Illinois side of the Saint Louis Air Quality Control Region, which is heavily industrialized, is under the jurisdiction of the Illinois Environmental Protection Agency through its regional office (State Region IV, Collinsville) and the central office at Springfield. The Surveillance Section is in charge of the emission inventory, which is continually revised and enlarged. Currently it contains information on about 2,500 sources, but it is expected to reach 14,000 sources. The inventory is in the form of a computer printout, and it is used constantly as a guide for issuance of permits (surveillance), as a source of information to other agencies and interested parties, and as an aid in modeling. The modeling is contracted to Argonne National Laboratories, the State Implementation Plan is based on the Argonne work. Emission inputs are shown in Table 8.

Table 8

EMISSION INVENTORY INPUT REQUIREMENTS
OF THE ILLINOIS ENVIRONMENTAL PROTECTION AGENCY,
AIR POLLUTION CONTROL DIVISION

Content of inventory	SO_2, CO, NO_x, HC, particulates
Time resolution	Quarterly, seasonal Daily during air pollution episodes
Spatial resolution	Point sources: UTM coordinates ±0.1 km Area sources by counties
Preferred medium	Printout, tape
Units	Engineering
Source descriptors	Stack height, exit velocity, temperature
Temporal variations	
Level of confidence	

5. Federal Highway Department, Department of Transportation, 400 - 7th Street, N.W., Washington, D.C.

The Federal Highway Department, in cooperation with the Air Data Office of EPA, will conduct a study designed to provide information on driving patterns on highways in the Saint Louis area. This information, in combination with emission data based on different driving modes, will permit an accurate assignment of the contribution of automotive traffic to air pollution in Saint Louis. The emission inputs necessary for this study will have to be developed from dynamometer runs under simulated driving conditions for the pollutants of interest (CO, hydrocarbons, NO_x).

E. The Planning Agencies

1. East-West Gateway Coordinating Council

The East-West Gateway Coordinating Council (Laclede Gas Building, Saint Louis, Missouri) is a coordinating agency created to facilitate the land use and transportation planning for the Saint Louis metropolitan area. It helps to coordinate the planning efforts of the Missouri State Highway Commission, the Illinois Department of Transportation, and various county and city planning departments. It has also received support from the U.S. Department of Housing and Urban Development and the Federal Urban Mass Transportation Administration.

The council has produced a comprehensive Transportation Study Report analyzing present problems and suggesting long- and short-range solutions to transportation needs based on socioeconomic projections, analyses of present traffic patterns, and estimates of future travel demands. The council has generated an "Average Daily Traffic Volume Summary" for the Saint Louis metropolitan area (1970), which is updated yearly and constitutes a valuable source of information on mobile sources.

The council, thus, is both a source and a user of data on mobile sources. Additional traffic data are available from

- The Illinois Department of Transportation, 930 St. Clair Avenue, Fairview Heights, Illinois (Mr. Robert Kronst, District Engineer).
- The Missouri State Highway Department, State Highway Building, Jefferson City, Missouri (Mr. Carl Klam, Highway Engineer).
- The Saint Louis County Department of Highways, 120 N. Gay Street, Clayton, Missouri (Mr. Richard Daykin, Director).
- The Saint Louis City Traffic Department, City Hall, Saint Louis, Missouri (Mr. Jim Bauman).

2. Industrial Waste Control Council

The Industrial Waste Control Council is an association of pollution control officers from the major industrial firms in the Saint Louis area. As the problems they face are to some extent common to all of them, they share technical information and develop public relations. Their members are probably in the best position to develop emission inventories for their respective companies, inventories which they need to satisfy legal requirements. The data thus developed are generally confidential and available only to organizations empowered to receive them.

F. Research Programs

1. Metromex

Metromex is a joint program involving groups from Argonne National Laboratory, Battelle Pacific Northwest Laboratories, University of Chicago, Illinois State Water Survey, Stanford Research Institute, and the University of Wyoming. It is basically a federation of individual scientists with diverse sources of funding, but common or at least complimentary research interests in the inadvertent weather modifications produced by large urban complexes through the interaction of their emission of pollutants and their contribution to the energy balance of the area. The study is centered in the Saint Louis area. Pollutants of interest to Metromex are primarily suspended particulate matter. Thus, major sources of particles, their physical properties and chemical analysis, and their size distribution are all parameters of interest.

2. Community Health and Environmental Surveillance System

The Community Health and Environmental Surveillance System (CHESS) is a national program that relates community health to changing environmental quality. It consists of a series of standardized epidemiologic studies designed to measure simultaneously environmental quality and sensitive health indicators in sets of communities representing exposure gradients for common air pollutants. The program is conducted by EPA in cooperation with local public health agencies, universities, and private research institutes. The purpose of the CHESS program is

- To evaluate existing environmental standards
- To obtain health intelligence for new standards
- To document health benefits of air pollution control.

One of the areas under study is Saint Louis.

As mentioned earlier, CHESS, like other health effect studies, requires primarily ambient concentration data rather than emission data. At present, it obtains such data from its own network of air monitoring stations sited within each CHESS community. Eventually, RAPS data may be used. Since historical data on ambient concentrations are generally not available, estimates of past pollutant concentrations have to be based on past emission data from which estimated ambient concentrations are derived via meteorological dispersion models. Thus, CHESS has some need for emission data. The CHESS program is administered by the Human Studies Laboratory at Research Triangle Park. The Bioenvironmental Measurements Branch is responsible for obtaining exposure data for the use of epidemiologists. Compounds of interest to these studies are shown in Table 9.

Table 9

EMISSION INVENTORY INPUT REQUIREMENTS
FOR CHESS STUDIES

Content of inventory	SO_2, NO_x, particulates, especially sulfates, nitrates,and organics (size fractionated, if possible), hydrocarbons, O_3, CO, trace metals, e.g., Cd, Zn, Pb, Hg, Cr, V, Ni, Cu, Mn, asbestos, benzo-a-pyrene, PCB, pollens
Time resolution	For acute studies: 1 to 4 hours For chronic studies: cumulative exposures
Spatial resolution	School districts
Preferred medium	Printout
Units	Gram/centimeter/second
Source descriptors	
Temporal variations	Seasonal
Level of confidence	

3. University Research

Individual researchers at several of the universities in the study area are engaged in work requiring knowledge of pollutant levels. For example, at Washington University, Dr. Richard Gardener is conducting work in the area of thermal pollution--"heat islands"--and constructing an aerosol submodel in conjunction with other agencies. Dr. Christopher Hill is studying the total (mining, processing, use, and disposal) environmental impact of certain industries. At the Center for the Biology of Natural Systems, Dr. Charles Lee is establishing pollution burdens in rain and soil samples and in human tissues.

At Saint Louis University, Dr. Slavin is studying the relationship of air pollution to health problems. There seem to be strong correlations between airborne sulfates and asthma attacks, between SO_2 and emphysema, and between carbon monoxide and heart attacks. His department is collecting a daily pollen count and could make it available to the RAPS inventory.

At Southern Illinois University, Dr. Al Kahn is carrying out studies of the carbon monoxide and hemoglobin reactions.

As mentioned earlier in this report, these activities have only a peripheral requirement for emission data at this point. However, to a certain extent, the format of the inventory should be designed with the potential to accommodate such data if they should become necessary.

4. Plant Damage

There are a number of compounds in the atmosphere that cause vegetation damage either by reducing yield and growth or by affecting the quality of the crop. Well over 90 percent of the losses are caused by the following pollutants:[8]

- Ozone
- Peroxyacetyl nitrate (PAN)
- Oxides of nitrogen
- Sulfur dioxide
- Fluorides

Out of 65 standard metropolitan statistical areas, the Saint Louis metropolitan area is rated by Benedict[8] 16th with respect to potential damage due to hydrocarbons, 24th with respect to oxides of nitrogen, and 18th with respect to sulfur dioxide on a scale that takes into consideration total emissions, meteorological factors, area, and stagnation periods.

Thus, plant damage constitutes a significant aspect of air pollution in Saint Louis, something that should be taken into account in setting up the emission inventory. Data on oxidants--ozone, PAN, and oxides of nitrogen--and sulfur dioxide would normally be covered by the inventory. It may be advisable to make provisions for a fluoride inventory as well. The main known sources of fluorides are aluminum, phosphate, and ceramic plants.

G. Conclusions

The emission requirements data for RAPS are such that inventories taken for other purposes--such as the Implementation Planning Program (IPP) or air pollution control agencies--are inadequate mainly in the degree of detail required for modeling studies. Since the verification of atmospheric dispersion models is an early and major goal of RAPS, the requirements of the modelers constitute the most important criterion of the adequacy of the inventory.

The most important requirements for modeling are

- Pollutants
  - From stationary sources: SO_2, CO, particulates, NO_x.
  - From mobile sources: CO, NO_x, particulates, hydrocarbons (by types).
- Resolution
  - Temporal: 1 hour
  - Spatial: Point sources--0.01 km.
    Area sources--variable size grid from 1 to 16 $(km)^2$.
- Units. Depends on model, but always metric.
- Output programs. Depends on model. Inventory should provide FORTRAN interface. Output to include source descriptors such as location (UTM coordinates), stack height, exit temperature, and velocity. For traffic models, description to include descriptors of roadway.
- Area. The area to be covered coincides with the boundaries of the Metropolitan Saint Louis Interstate Air Quality Region. Alternatively, it could be resolved to a smaller, more central area covering only the City of Saint Louis and the Counties of Saint Charles, Jefferson, Saint Louis, Monroe, Madison, and Saint Clair (Figure 1).

- **Time.** The period will vary considerably. In some cases, model verifications will be limited to relatively short periods (48 to 72 hours).

The requirements of other study groups, such as the health study workers, are more extensive, but generally less intensive. They require the system to store and retrieve information on many compounds, but the demands for spatial and particularly temporal resolution are much less critical.

Special programs, such as Metromex, have specific requirements for certain categories of pollutants, which may or may not be satisfied by a general emission inventory.

IV TASK B: EMISSION INVENTORY CONTENT

A. General Principles

1. Introduction

As is shown in Section III, there are numerous agencies and groups--both inside and outside the RAPS program--that have actual or potential needs for emission inventory data from the Saint Louis Air Quality Control Region (AQCR). Wide differences exist in the specific data requirements of these agencies, particularly with respect to the time resolution of the estimated emissions. However, the most demanding requirements are set by the need to verify experimentally various multi-source atmospheric dispersion (air quality) models. In particular, the emission inventories used for this purpose must provide a high degree of time resolution, giving emission estimates at one-hour intervals. A high degree of spatial resolution is also required.

Other possible users of emission inventories surveyed under Task A have generally far less demanding requirements. In particular, they do not commonly need the refinements of time resolution required for short-interval dispersion modeling. If they use the emission data for air quality modeling at all, it would probably be to estimate relatively long-term, average pollutant concentrations. Others may use inventory data only for surveillance and for determining the priorities for regulatory programs. In any case, the high-resolution emission inventory designed for use in dispersion model verification will be more than adequate for any of the other uses.

Attempts have been made previously to verify experimentally predictions of short-term air quality made from dispersion models. However, the source emission data fed into the dispersion models have been derived primarily from long-term average emissions (e.g., annual emissions), at least for stationary sources. Furthermore, most of the annual emission data have been derived by applying emission factors to survey information on fuel consumption and materials flow, rather than by making direct measurements. Estimates of hourly emmissions have been derived or extrapolated from the annual rates by more or less elaborate calculation procedures (see Section VII). The resulting compilation of extrapolation procedures, algorithms, and correlations for simulation of short-term emissions may be described, for lack of a better term, as an emission model. Unfortunately, the errors and uncertainties, both in the basic data and in the assumptions required for their extrapolation, are so great (or so indefinite) that estimates of hourly emissions derived from gross annual emissions cannot be relied upon for the critical tests of short-term air quality predictions to be carried out in RAPS.

At best, the predictions of pollutant concentrations from an air quality model can be no more precise than the source emission data used as input to the model. In addition to errors in emission data, other sources of error in the predictions, besides the inherent limitations of the dispersion model itself, include the description and measurement of the atmospheric structure, the measurement of the actual pollutant concentrations, and the representativeness of the pollutant concentrations actually measured. Assuming that sufficient care is exercised, we can estimate source emissions more accurately than any of the other input data to the air quality model. The level of effort needed to ensure the accuracy of the emission estimates rises rapidly as the required accuracy is increased, particularly as the time resolution is extended to shorter and shorter periods. Nevertheless, the emission estimates, being the least equivocal of the inputs to the air quality model, should be made accurately enough to ensure that they do not become the limiting factor in the testing of the model.

There is no practical way by which the emissions from all sources can actually be measured during the particular hours in which the test of an air quality model is carried out. Consequently, it is necessary to employ simulation techniques to estimate the hourly emissions from most sources, a process that also can be described as emission modeling. However, such emission modeling should involve as little extrapolation of data as possible. In particular, the emission model for a particular source should, where possible, contain an independent variable to be evaluated from data collected in real time at the source. Such data can, as in an extreme case, indicate whether the source was actually in operation during the period of time under consideration. In the general case, the data should indicate the value of some variable having a functional relationship to the emission. Most directly, in sources having continuous monitoring systems, the variable may be the concentration of the specified pollutant in the waste gas. In other cases, it may be a quantity such as the rate of firing of fuel. At all important sources, the relationship between the emission and the chosen independent variable should be established from actual measurements. Such measurements essentially constitute a calibration of the emission model. It will, of course, be necessary to redetermine the relationship between the independent variable and the emission (recalibrate the model) whenever there are significant changes in the mode of operation of the source.

It is feasible to carry out an emission inventory of the foregoing type for the Saint Louis AQCR and to store hourly values of the chosen independent variables and of the corresponding emission estimates for an appropriate period (for two or three years if desired). However, the process is necessarily difficult, time consuming, and expensive. It should therefore be carried out only for the minimum number of pollutants necessary for verification of atmospheric dispersion models; as discussed in Task A, these are considered to be SO_x, NO_x, HC, and CO. The inventory, which should be adequate for use in verification of mesoscale atmospheric dispersion models, may be designated as the RAPS Emission Inventory.

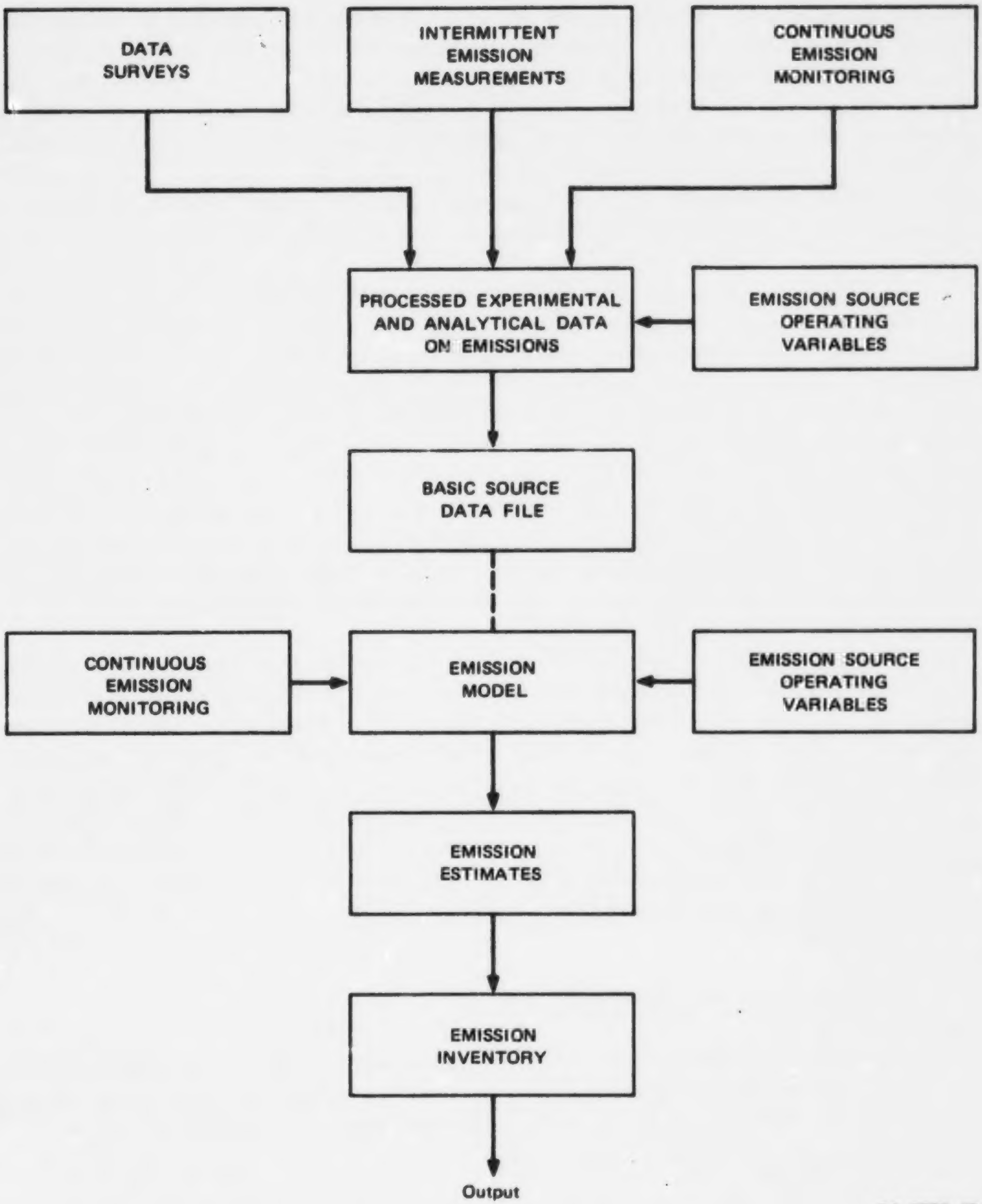
It should be appreciated that the RAPS Emission Inventory will be essentially separate and distinct from the existing National Emissions Data System (NEDS) Inventory, which was compiled under far less demanding criteria. Some information from the NEDS Inventory will be useful in the RAPS Inventory; for example, the NEDS Inventory locates and identifies stationary point emission sources and indicates their relative magnitudes. Some of the data in the NEDS Inventory relative to area sources and some small point sources may be, if carefully evaluated, adequate for inclusion in the RAPS Inventory. In addition, NEDS will provide the needed data on emissions for purposes that do not require high resolution data of the principle pollutants covered by the RAPS Emission Inventory.

For some anticipated microscale atmospheric dispersion studies, very high degrees of temporal and spatial resolution of emissions may be required for specific, small areas. Again, for particular studies, higher resolution data may be required for a pollutant and included in the RAPS Emission Inventory. The precise requirements for emissions data in such cases will vary considerably, and cannot be anticipated at this time. Specification and execution of these special emission data collections are basically research tasks that will be best handled by the research project staff carrying on the dispersion studies.

2. The Emission Inventory System

The following discussion is intended to provide an understanding of the general process by which information is generated and flows through the proposed RAPS Emission Inventory system and is intended to present definitions of terms (see Figure 2).

It should be appreciated that, whereas the eventual emission inventory is organized primarily according to pollutants, the execution of the inventory is necessarily organized primarily according to sources (the manner in which the original data must be obtained). The process


DATA SURVEYS
INTERMITTENT EMISSION MEASUREMENTS
CONTINUOUS EMISSION MONITORING
PROCESSED EXPERIMENTAL AND ANALYTICAL DATA ON EMISSIONS
EMISSION SOURCE OPERATING VARIABLES
BASIC SOURCE DATA FILE
CONTINUOUS EMISSION MONITORING
EMISSION MODEL
EMISSION SOURCE OPERATING VARIABLES
EMISSION ESTIMATES
EMISSION INVENTORY
Output

SA-2579-42

FIGURE 2 EMISSION INVENTORY SYSTEM

by which the RAPS inventory is to be carried out is essentially conventional; however, the special emphasis on and treatment of certain steps is determined by the high degree of temporal and spatial resolution required to meet the specific requirements of RAPS such as verification of atmospheric dispersion models.

Original information from emission sources is to be compiled from data surveys and, as far as possible, directly from intermittent measurements or continuous monitoring of the sources themselves. Subsidiary data on the operating variables and parameters of the sources must be collected so that correlations can be made between the variables and parameters and the actual measured emissions. The source variables are to be quantities that are--or can be--routinely measured as part of the source operation. Hence, once a correlation is established, the measurement of the variable can be substituted for the more difficult operation of measuring the actual pollutant emission.

For a relatively small number of the largest point sources, it is anticipated that continuous analyzers will be installed to monitor the concentration of key pollutants (SO_2 and NO_x). For the remaining point sources as far as practicable, reliance must be placed on intermittent manual measurements of emissions correlated with continuously measured process variables as described above, rather than upon the use of existing emission factors, although the latter can be used in certain cases.

For the smaller point sources, and for area and line sources (stationary and mobile), individual emission measurements will not be made, but more accurate emission factors than are currently available for typical sources must be derived from a sampling program.

Processing procedures for the raw data will depend on the nature of the information. At least initially, computation of the emissions from raw experimental data will probably be most conveniently carried out manually. Once the processed data is suitably organized, it is to be stored in the Basic Source Data File, which then is the source of information required for creation of the Emission Model for each source category of sources.

The emission model in this context is essentially a collection of correlations or algorithms that permit calculation of estimated emissions from readily or routinely measured operating variables and parameters of the various emission sources (as discussed above). The relationships must be worked out from the basic source data; they may range from simple to complex, depending on the nature of the emission sources.

To generate specific emission estimates, it will be necessary to supply to the emission model particular values of the independent emission source variables pertinent to the desired time interval. These input data must be collected from the sources on a continuing basis over whatever time period is required. The Emission Estimates thus generated provide the input to the Emission Inventory.

The Emission Inventory will consist of the compiled and stored estimates of the hourly emissions of the specified pollutants on an hourly basis for the time period (two or more years) of interest to the RAPS program. The emission estimates corresponding to any chosen sequence of one-hour intervals will then be withdrawn from the Emission Inventory to form input for the air quality models and other purposes.

B. Precision of Emission Estimates

Since the requirements for the emission inventory are to be set by the needs of dispersion modeling, it is necessary to specify, within some limits, what degree of agreement between predicted and measured pollutant concentrations will be considered to constitute a verification of a dispersion model. While the work of Hilst[9] discussed below approaches this issue, no such specification of model precision has been made. Modelers have thus far simply striven to obtain the best results that they could get. In tests of models made to date, it has been common to encounter deviations of ±50 to 100 percent or more between predicted short-term pollutant concentrations and the measured values. Better results are reported for prediction of long-term average concentrations.

An ideal multisource atmospheric dispersion model would permit accurate prediction of the concentration of a specified pollutant at any desired point in the geographical region of interest over as short a time interval as might be of practical interest. In practice, it is necessary to compromise the requirements for the model with respect to both temporal and spatial resolution. In addition to the inherent limitations of a model itself, the precision of measurement of emissions and meteorological variables and the practicability and precision of measuring atmospheric pollutants in the field set practical lower limits on the time intervals and the receptor areas that can be considered.

The predicted pollutant concentration is assumed to represent the average value within one square kilometer, which is the smallest element of the standard geographical coordinate grid. The pollutant concentration measured by a single monitor will bear a relation to the average concentration that will be determined by the distribution of the pollutant over the specified area. The distribution of the pollutant will depend on the geographical and topographical characteristics of the area. The distribution will therefore vary not only from one grid area to another, but also within any one grid area under different circumstances and at different times.

Other experimental studies in the RAPS program are expected to address the problem of the spatial variation of pollution concentrations within the receptor area. However, where it is necessary to employ a single monitor for one square kilometer area, the relationship of the measured concentration to the true average concentration for the area will necessarily be statistical and subject to a greater or lesser degree of uncertainty.

For such studies, or the development of microscale submodels designed to couple the regional scale models to specific localities or points where measurements are made or air pollution effects are significant, special efforts must be made to collect detailed emission data on an experimental basis. The routinely collected data of the RAPS Emission Inventory should be designed to serve the broader scale needs of the modelers on a continuing basis.

It will be important, however, to make a special check in the vicinity of each permanent monitoring station (say within a radius of one kilometer) to ensure that any point or other source that could significantly effect the representativeness of readings made at the monitoring station, are taken into account. For example, it may be found necessary to treat an office building heater system efflux as a specially considered point source, rather than as part of a nonspecified area source. Alternatively, if such consideration cannot be made in connection with the emission inventory system, steps should be taken by those responsible for air quality monitoring to develop weighting or calibration factors for the station in question, or even to set its readings aside for certain purposes under particular wind conditions

As stated above, it is essential that the precision of the pollutant emission data not limit the precision of the dispersion model. The difficulty of attaining highly precise measurements or estimations of pollutant emissions increases rapidly as time intervals are shortened. Hence, it is necessary to make compromises between precision and the cost and difficulty of measurement and estimation.

The question of the significance of errors in specifying the strength or location of sources has been addressed in Section VII, especially in terms of the precision needed in defining position. The sensitivity of air quality models to such errors is a complicated question and specific to each model and each area. The work of Hilst[9] in a case study of the TRC Model in Connecticut is indicative of what can and should be done for the major models to be tested in the RAPS program. Depending upon the resolution in space and time of the predictions made by an air quality model, Hilst's findings in New England are encouraging because the cancelling effect of random uncertainties minimizes the errors due to inaccurate point source data. Most serious errors can result from systematic inaccuracies, such as those introduced by incorrectly estimating area sources, and the smaller the proportion of the total inventory reported in this way the better. It is recommended that as early as possible, specific studies (based initially on NEDS data) of the type reported by Hilst be performed to provide information on the effects of varying the degree of precision of emissions data in Saint Louis, especially in terms of hourly resolution. In the meantime, it is highly desirable to develop the most detailed and accurate emissions database economically feasible in Saint Louis, both to ensure the best support of the air quality model studies and to provide the base data for research in emission modeling methodology.

C. Inventory Resolution

1. Temporal Resolution

As is indicated above, the difficulties both of formulating an adequate dispersion model and of testing it increase rapidly as the time interval is shortened. Ideally, a model should be capable of predicting the atmospheric concentration of a pollutant over the shortest interval for which an air quality standard is specified. In fact, it is probably impractical to specify an interval shorter than one hour. One limitation is that it is practically impossible to specify significant values for the pollutant emissions from most sources for periods of less than one hour. Indeed, it is difficult even to make precise estimates of emissions for periods as short as one hour, at least without making direct measurements in the particular time interval of concern. In view of these considerations, the minimum time interval to be considered may be set at one hour. This degree of time resolution has been accepted by most modelers.

2. Spatial Resolution

Stationary sources fall into two categories: point sources and area sources. The distinction between the two is generally arbitrary; point sources are those having emissions of a specified pollutant in excess of some selected minimum value, and they are treated individually. Smaller sources within a selected region are aggregated, and their total emission is assumed to arise uniformly from the area.

Choice of the minimum emission rate for specification of a point source obviously depends on the nature of the pollutant and the ratio of the emission from the particular source to the total emission from all sources.

Specification of the location of a source, whether a point or an area, is to be made by reference to UTM coordinates. The precision required in specifying the position of a source is also partly related to the position of the receptor. Some dispersion modelers have asked that the position of point sources be determined within ±10 meters. From the standpoint of a nearby receptor, the physical size of the stack or vent may be appreciable; large stacks may be 10 meters or more in diameter, and some building vents may be still larger in their principal dimension. An objective method for determining the spatial resolution required is presented in Section VII.

The method enables one to estimate the allowable error Δy, in the cross wind position of a source (for any specified stack height, source strength, wind velocity, and stability conditions), as it affects pollutant concentrations at given downwind distances. "Allowable error" is defined arbitrarily by comparison with a reference source strength--e.g., the 100 tons/year commonly used as the lowest value for point sources, and a reference positional error--e.g., 100 m, the resolution of most current inventories.

Although such a high degree of precision in specifying location may only be necessary in a limited number of applications, it is recommended that wherever possible the location of point sources be reported with a resolution of ±10 meters. Although existing data (in NEDS) is only specified to ±100 meters, additional surveys of significant sources will have to be made in any case, and it would therefore be readily possible to obtain the further locational data at that time.

As noted above, verification of microscale dispersion models will generally be special exercises. They will require finer spatial resolution and more detailed specification for local sources than will be required for tests or use of the mesoscale models. This finer degree of resolution can be incorporated into the general emission inventory for the entire area covered by the major dispersion models. However, the additional time and cost required may not be justified, since the increased resolution will probably never be required except in relatively few small areas being treated in the microscale dispersion studies. It is more practical to make special, fine-resolution inventories for the particular limited areas of the microscale studies.

D. Pollutants

1. General Discussion

Initially, inventories must be carried out for those pollutants that are to be used in model verification. In principle, it would be desirable to carry out the inventories simultaneously for as many of the pollutants as possible, particularly where surveys of the same sources are involved. But in practice, it may not be entirely feasible to do this, because the basic data may simply not be available for all of the pollutants at the same time. Acquisition of adequate data on emissions of nitrogen oxides and hydrocarbons will probably take much longer than will the gathering of equivalent information for sulfur oxides.

2. Nonreactive Gases

Although none of the major pollutant gases that may be used in tests of dispersion models are actually nonreactive, both sulfur dioxide and carbon monoxide are relatively unreactive in relation to the time of dispersion that is of primary interest to dispersion model verification. Carbon monoxide is the more inert of the two. However, sulfur dioxide has the advantage that its reaction products (sulfuric acid mist and sulfates) can be traced by chemical analysis, whereas the identity of carbon monoxide is lost after reaction.

Carbon monoxide is best suited to testing models of dispersion from automotive sources, since these are by far the major sources of this pollutant. It will be necessary, nevertheless, to inventory stationary sources, since their contribution to the ambient concentration of carbon monoxide may be appreciable in relation to the model testing.

It has been found that large quantities of carbon monoxide are produced in nature by the oxidation of methane in the atmosphere. Carbon monoxide is removed from the atmosphere by microorganisms in the soil. The background concentration of carbon monoxide in the atmosphere is determined by the balance of the natural removal processes and of the natural and anthropogenic formation of the compound. It is unlikely that either natural formation or natural removal is important on the time scale of concern to the dispersion studies and within urban areas, where high concentrations of carbon monoxide may be generated. Task E presents a more detailed discussion of natural emissions.

Sulfur dioxide is best suited to use in testing of dispersion models for pollutants from stationary sources, since relatively little is emitted from mobile sources. It is more reactive than carbon monoxide and more subject in the atmosphere to the action of various removal processes. The oxidation of the sulfur dioxide to sulfur trioxide results in conversion to an aerosol (sulfuric acid mist), and subsequent or coincident reaction of the sulfuric acid with ammonia or other basic materials in the atmosphere results in formation of solid aerosols. If the time interval of interest to the dispersion study is no more than a few hours, these reactions will probably not be of great consequence. Fortunately, it is possible to sample for both sulfur dioxide and the sulfate aerosols and, thus, to deduce the probable history and dispersion pattern of the total sulfur originally being discharged to the atmosphere as sulfur dioxide. (About two to three percent of the sulfur emitted from combustion processes is usually already in the form of sulfur trioxide.)

Sulfur dioxide and its reaction products may be removed, or scavenged, from the atmosphere by a variety of mechanisms. The sulfur dioxide may be absorbed by vegetation or reactive solid surfaces or be adsorbed by a variety of solid surfaces. It may also be absorbed by rain drops. The sulfuric acid or sulfate aerosols may be rained out or washed out or may be mechanically deposited by inertial, diffusional, or gravitational mechanisms. In time, the aerosols will also coagulate, increasing the particle size and accentuating particle deposition by the inertial and gravitational mechanisms. The coagulation mechanism will be strongly affected by the total concentration of particulate matter present in the atmosphere

In general, the influence of the various removal or scavenging processes on sulfur dioxide should be much greater than the corresponding influence on carbon monoxide. Allowances must nevertheless be made for the depletion of both pollutants by the various removal processes, but determining these adjustments is, of course, a task separate from the emission inventory. Estimating the depletion of the emitted pollutants is, in fact, an inherent part of the formulation and development of the dispersion models. It will call for an extensive supporting experimental program.

3. Reactive Gases

The most important transformation process involving major air pollutants is the photochemical reaction of the nitrogen oxides with hydrocarbons to form PAN and ozone. The nitrogen oxides are contributed in roughly comparable amounts by both stationary and mobile sources, which also contribute the hydrocarbons. Consequently, it is necessary to devote comparable attention to an inventory of emissions of both of these types of pollutants from both classes of sources.

As they are present in waste gases at elevated temperatures, the nitrogen oxides are primarily in the form of nitric oxide (NO). Partial conversion of the NO to nitrogen dioxide (NO_2) takes place primarily after the waste gases are cooled and mixed with ambient air. There appears to be no compelling reason why the distribution of NO and NO_2 in the hot waste gases need be determined or specified as part of the emission inventory. The subsequent distribution of the two species in the atmosphere is, of course, of critical concern in the transformation models, but it will have to be determined from separate experimental and analytical studies.

Developing an inventory for nitrogen oxides presents special problems. Most of the nitrogen oxides are formed by fixation of atmospheric nitrogen at elevated temperatures in the combustion processes, and the quantity formed is dependent on the temperature reached, the residence time at high temperature, the size and configuration of furnace or other combustion devices, the amount of excess air present, and any other factors that may influence the time and temperature history of the combustion gases. The nature of the fuel also influences the formation of nitrogen oxides, primarily through those fuel properties that affect the time and temperature relationships--flame temperature and flame emissivity. Any nitrogen compounds in the fuel may also be partly oxidized. Hence, the quantity of nitrogen oxides emitted from a given piece of combustion equipment cannot be estimated from first principles by any currently available methods. Strictly, it must be determined experimentally for each device and each operating condition.

Fortunately, the range of variation in nitrogen oxides formation is not so great that reasonably representative values cannot be obtained by testing specific types of devices over appropriate ranges of operating conditions. Nevertheless, extensive source sampling will be required to obtain adequate information for a precise emissions inventory.

Inventory of the hydrocarbon gases and vapors presents a potentially complicated case because of the very large number of different organic compounds that may be emitted and that may also vary widely in photochemical reactivity. It is completely impractical even to attempt to inventory emissions compound by compound, except in instances where, for example, a relatively pure, known compound is lost by vaporization. Probably the most that can be done in a practical way is to identify the organic compounds by major groups or classes (e.g., paraffins, olefins, diolefins, aromatics, alcohols, ketones, and so on). For the most part, even this will require a major source-sampling program. Identification and quantitative determination of the classes of compounds, alone, will call for a large analytical effort. Hence, it is essential to keep the scale of the sampling and analysis to a minimum consistent with attainment of the program objectives.

4. Particulate Matter

The development of dispersion models for particulate matter, as well as efforts at verification, are well behind comparable developments for dispersion models for gases. The dispersion of particulate matter is more complex than that of gases, since the dynamics of the particles are strongly affected by the particle size, as are the removal processes that result in a decay of the particulate cloud. In addition, the nonspecific nature of most particulate matter makes it difficult, if not impossible, to identify the source of the material, trace its path from source to receptor, and allow for losses resulting from removal processes.

In using simple dispersion models, it has been common for workers to assume that all dust emitted from emission sources remains airborne and contributes to the resulting atmospheric concentration of suspended particulate matter at the receptor. Such an assumption is highly unrealistic, since relatively coarse particles will, in fact, tend to settle out. Relatively fine particles (about 10 microns in diameter and smaller) are frequently assumed to behave more or less like a gas; this is a fairly safe assumption, but one still subject to somewhat indeterminate errors.

Making a realistic test of models concerned with particulate formation or dispersion would require the following information:

- The quantity of particulate material emitted from each source and the distribution of effective particle sizes of the particulates. It should be noted that the effective particle size distribution, which may reflect particle flocculation, is not necessarily the same as the distribution that may be indicated by the measuring techniques commonly employed.

  The particle size should, of course, be expressed in terms of the Stokes diameter (i.e., the diameter of the equivalent spherical particle of the same density that would have the same terminal settling velocity as the particle in question).

- The extent to which particles of each size are deposited by removal processes during passage over the terrain between the source and the receptor. No essential quantitative information is available on these phenomena. The technical problem is similar to that of determining the efficiency of dust collection equipment in the collection of particles of various sizes. However, the studies of particle deposition from the open atmosphere are necessarily less controllable than experiments with dust collectors, and work in even the latter field is not well advanced from the standpoint of basic science and technology.

Determination of the mass emissions and particle-size distributions of particulates emitted from even the major sources alone would require a major experimental program. The experimental methods and procedures for determination of the effective particle size of the materials as emitted are still poorly developed. In addition, the study of particle deposition from the atmosphere calls for a far greater experimental effort. If a comprehensive effort is to be made at confirmation of particulate dispersion models using particulates normally discharged from various sources, a lengthy and costly preliminary experimental and theoretical investigation will be required. Although information on particulates is noted as a requirement by a number of users identified in Task A, there is no evidence that the implications of including such data have been seriously considered.

It is therefore open to question whether an attempt to verify particulate dispersion models should be made using the actual particulates emitted from various sources. An alternative procedure using particulate tracers may be usable with less preliminary work and less expense and at an earlier date.

Use of particulate as well as gaseous tracers has already been proposed as a part of the RAPS program for tracing wind movements and plume dispersion. Conversely, it is possible to use synthetic particulates prepared from tracer materials (e.g., dyestuffs) to test predictions of particulate concentrations at various receptor areas, and also to get a relatively direct measurement of the depletion of the particulate cloud in its movement from source to receptor. The synthetic particulate matter can be produced within reasonable ranges of desired particle size, and it can be discriminated from other particulate matter in the atmosphere by its chemical or physical characteristics. The most convenient materials of this kind are those that can be measured by colorimetric or fluorometric techniques.

If the synthetic particulates can be used for the testing of the dispersion models, there will probably be no need to develop a particulate emission inventory that has a high degree of resolution with respect to time intervals and particle-size distributions. This will result in major savings of both cost and time.

For the other purposes of RAPS, e.g., research on transformation processes, there may be a need for detailed information on particulate concentrations with high temporal and spatial resolution. Because of the difficulties noted above, however, it is suggested that research studies for these purposes be planned to avoid, as far as possible, dependence upon general source emissions data. Better results can be achieved by special monitoring of only the critical sources in a carefully selected area. The alternative is an extremely costly and difficult inventory development program.

In summary, it is proposed that data on particulates should not be included in the high-resolution RAPS inventory emission, since the means are not currently at hand either to acquire the full range of data that may in principle be required or to employ the information effectively if it were obtained.

5. Other Pollutants

In the RAPS area, only a few agencies have indicated an interest in obtaining inventories of pollutants other than the major ones discussed above, and none of the agencies that did were concerned with short-term dispersion modeling. Local and state regulatory agencies were interested in emission inventories for designated hazardous air pollutants, including mercury, beryllium, cadmium, lead, and asbestos. They called only for quarterly or yearly average emission rates or, at most, for daily average emissions during air pollution episodes.

The CHESS program includes consideration of a wider number of trace materials as pollutants including cadmium, zinc, lead, mercury, chromium, vanadium, nickel, copper, manganese, asbestos, benzo-a-pyrene, and polychlorinated biphenyls. Although CHESS relies mainly on air concentration measurements obtained from its monitoring network, it will probably require estimates of relatively long-term average concentrations in the years before the air monitoring network was established. Thus, it may be necessary to prepare estimates of emission rates for these earlier periods, so that the atmospheric concentrations at those times can be calculated from use of dispersion models.

In general, there is little point in attempting to carry out emission inventories for pollutants other than the major ones discussed above until such time as the precise requirements are specified by the potential users. Variations in the required precision and the time and space resolution can greatly change the costs and time required for the inventory.

6. Heat and Water Vapor Releases

Although not pollutants, sensible heat and water vapor releases are of interest to meteorology and dispersion modeling because of their effects on atmospheric stability. Studies are now being made of the effects of the urban "heat island."[10] The sensible heat and water vapor content in waste gases can generally be calculated readily from data that will be collected in the course of the emission inventories for sulfur oxides, nitrogen oxides, and particulate matter. The heat transferred to the atmosphere by convection and radiation from the surfaces of buildings, paved areas, and the earth must, of course, be estimated by separate procedures not related to the emissions inventory.

The temperatures and volumetric flow rates of the waste gases will be part of the information collected during the inventories. Hence, it will be possible to calculate the sensible heat content of the gases above the ambient temperature level. For combustion processes, it will generally be possible to calculate the water vapor emission from the quantity and the hydrogen content of the fuel burned. For some other fuel-burning operations, such as direct-fired drying, the water vapor present in the waste gas will greatly exceed that formed by burning of the hydrogen in the fuel. However, the water vapor content of the gas may be obtained during the sampling for various pollutants. Sometimes data on the process may permit calculation of the water content of the gas.

E. Source Categories

1. Classification Scheme

A general classification scheme for emission sources is presented in Table 10. It is broad enough to encompass all emissions of pollutants from all sources. The source categories (stationary and mobile) and subcategories (area, line, and point) are convenient from the standpoint of dispersion modeling as well as from inventory organization. The division of source processes into combustion and

Table 10

CLASSIFICATION OF SOURCES FOR EMISSION INVENTORY

Source Category	Stationary Sources				Mobile Sources	
Source Subcategory	Area Sources		Point Sources		Area and Line Sources	
Source Process	Combustion	Noncombustion	Combustion	Noncombustion	Combustion	Noncombustion
Source units	Commercial Institutional Residential Small industrial Fuel Use Space heaters Water heaters Boilers Waste disposal--incinerators	Commercial Small industrial--Venting of organic vapors (dry cleaning, painting, gasoline storage and handling, food preparation)	Utilities Power plants Municipal--incinerators Industrial Boiler and power plants Indirect-fired air and process heaters Stationary internal combustion engines Stationary gas turbine engines Incinerators	Industrial Direct-fired process units All other industrial processes, material storage and handling	Surface vehicles Passenger cars Trucks and buses Commercial vehicles Railroads Vessels Off-highway vehicles and equipment Aircraft Piston engines Gas turbines	Surface vehicles and aircraft Venting of fuel vapors Wear of tires and brakes
Pollutants	Gases and vapors SO_x NO_x CO Hydrocarbons and derivatives HCl HF Odors Particulates Fly ash and its specific chemical components Smoke	Gases and vapors Organic vapors (solvents, gasoline) Odors Particulates Organic aerosols Smoke	Gases and vapors SO_x NO_x CO Hydrocarbons and derivatives HCl HF Odors Particulates Fly ash and its specific chemical components Smoke	All pollutants	Gases and vapors SO_x NO_x CO Hydrocarbons and derivatives Odors Particulates Smoke Lead Oil aerosols Derivatives of fuel additives	Hydrocarbon vapors Particulates Organic Inorganic

noncombustion processes is a convenient one that is not subject to serious ambiguities. Combustion processes are here defined as those in which the release of pollutants comes solely from the burning of fuels or wastes. They include all processes in which there is indirect transfer of the heat produced (e.g., water heaters and boilers, indirect-fired air heaters) as well as incinerators, internal combustion engines, and gas turbines.

Noncombustion processes comprise all other pollutant sources not falling under the specific definition of combustion processes given above. In many of them, combustion of fuels actually does take place, but the products of combustion come into contact with other process materials that may give rise to pollutant emissions; examples are direct-fired driers, calcining kilns, cement kilns, and paint-baking ovens. In other cases, the process emitting pollutants may have no direct contact at all with products of fuel combustion; many processes for manufacturing organic chemicals are in this class. Heating of such processes is by indirect transfer from combustion processes that they themselves constitute separate combustion sources. Still other processes involve only venting or ventilation, with consequent release of pollutants to the atmosphere; examples include dust emissions from flour mills and solvent emissions from paint spray booths.

2. Stationary Sources

a. Point Sources

Combustion Sources--The major point combustion sources are utilities and industrial plants. The largest industrial sources are commonly the power and steam plants. However, there are other types of indirect-fired process heaters (e.g., pipe stills in petroleum refineries) that are used for heating various kinds of process fluids and heat transfer media other than water.

Utility power plants handle a fluctuating generating load that usually follows a fairly well-defined cycle. The typical load passes through a minimum in the early morning hours. The absolute levels and the hours at which the minimum and maximum loads are reached are functions of the season of the year. Summer and winter loads reflect the effects of air conditioning and space heating loads. The patterns for different power plants may vary widely, however, depending on whether a plant is handling a base load or is being used for peaking.

Industrial power and steam plants will usually display load patterns substantially different from those of the public utility plants serving the general area. Where the manufacturing plants are operated on a 24-hour basis, both the electrical power and the steam required for process use should in general represent fairly steady loads. On the other hand, the power and steam plants will be essentially if not completely shut down when the manufacturing plant is out of operation. The power and steam required for heating and air conditioning the plant will superimpose a fluctuating load on that resulting from process requirements.

The nature of the load cycle in an industrial power plant will also be affected if the plant is tied into the public utility power grid. In such cases the plant will usually send power into the public system when power demand is low in the manufacturing plant and draw power from the public system when demand is high.

Depending on the type of manufacturing, electrical loads may exhibit cyclic behavior, sometimes over relatively short intervals (e.g., electrical power loads in a steel rolling mill). Batch chemical processes may have a cyclic steam demand.

To obtain a significant emission inventory from such sources, particularly an inventory from which it is possible to simulate one-hour emissions, it is necessary to acquire detailed knowledge of the operating cycle of each installation as well as of the characteristics of the installation itself, the fuel or fuels used, and so on. A sampling program to acquire information for derivation of representative emission factors will have to be carried on.

Although emissions from such sources are commonly estimated by emission modeling techniques (as described in Section VII) using information on load and operating patterns discussed above, we recommend that, wherever possible, emission data from the point sources responsible for the major proportion of emissions be acquired by direct methods using information on actual emissions, loads or fuel consumption. Details of this approach are given below.

Incinerators constitute another point combustion source. The sulfur contents of common wastes are low, so that incinerators are only rarely significant sources of sulfur dioxide. The variability of the composition of wastes will, however, make it much more difficult to correlate the measured emissions with operating variables than with fuel-burning combustion sources.

The design of most existing incinerators has not been favorable to efficient combustion, so that emissions of carbon monoxide and hydrocarbons tend to be much higher than in fuel-burning operations. This problem is frequently aggravated by improper operating conditions. The formation of nitrogen oxides can vary widely depending on incinerator operating temperatures as they are affected by the amount of excess air used in combustion.

Since the variations between different incinerators may be extreme, emissions are relatively unpredictable. Hence, any large units (municipal incinerators and possibly some industrial incinerators) should be tested individually, i.e., on the basis of operating data, such as daily tonnage of throughput. Smaller industrial and commercial incinerators may be treated by modeling with only representative units being sampled, since their emissions will be small enough to be estimated with adequate precision from such data.

Noncombustion Sources--Noncombustion point sources of pollutants are practically exclusively industrial in nature. They comprise such a diverse collection of manufacturing operations that no generalizations can be offered concerning either their emissions of pollutants or the factors affecting them. Most noncombustion point sources will emit one or more of the pollutants of concern to the dispersion model studies, as is shown in the following discussion under each pollutant.

The principal point noncombustion sources of SO_2 are found in petroleum refineries, nonferrous smelters, sulfuric acid plants, and--possibly--integrated steel mills.

In petroleum refineries, the process sources are the Claus sulfur plants, the regenerators of catalytic cracking units, and flares burning waste sour refinery gases. Refinery process heaters or boiler furnaces burning sulfur-containing fuels (including sour refinery gases) fall in the category of point combustion sources discussed above. The flare represents only a combustion source, but it is one of such specialized nature that it is best classified with the process sources. Because of its irregular operation, the flare presents special problems of emission estimation, which must be worked out in reference to process measurements available and with consideration of the actual level of SO_2 emmissions for which the source is responsible. Claus sulfur plants are likely to be fitted with continuous monitors for measurement of SO_2 in the tail gases. In the event that they are not, manual measurements of SO_2 emissions must be made and correlated with an available measured process variable, such as sulfur production rate. Measurements of NO_x emission, also required, will probably have to be made manually. The regenerator of a catalytic cracking unit is not only a source of SO_2 but (at least potentially) a major point stationary source of CO. The actual emission of CO depends on whether the regenerator is fitted with a CO boiler and on the combustion efficiency of the CO boiler. The SO_2 emission is related primarily to the sulfur content of the petroleum feedstock being processed in the catalytic cracking unit. Measurements must be made of the SO_2, CO, and NO_x concentrations in the waste gases and of the waste gas flow. The quantities can probably be correlated with the throughput rate of catalyst being regenerated. The sulfur content of the cracker feedstock will be an added parameter of the SO_2 emission.

In secondary nonferrous smelters, the principal source of SO_2 emission is likely to be the fuel used, and the measurements and correlations of the emissions will be similar to those employed in combustion sources. However, primary smelters operating on sulfide ores are potentially major point sources of SO_2 emissions. Apparently, there are no primary nonferrous smelters operating in the Saint Louis area completely without SO_2 recovery (by manufacture of sulfuric acid). However, the tail gases from the sulfuric acid plants operating on smelter gases can themselves be major sources of SO_2 emission, as noted below.

Contact sulfuric acid plants, whether sulfur-burning units or by-product acid plants, are at least potentially major sources of SO_2 emissions. In the future, at least, they will probably be equipped with continuous monitoring devices for measurement of the SO_2 concentration in the tail gases partly for process control. Whether manual or automated, determinations will have to be made of SO_2 and NO_x concentrations and waste gas flow rates. The results must then be correlated with operating variables, such as the acid production rate.

Integrated steel mills have a common major source of actual or potential SO_2 emissions--the production of coke oven gas--which has a substantial sulfur content. If the coke oven gas is not desulfurized before use, the sulfur will be emitted as SO_2 from the various combustion sources (e.g., power houses, underfiring of coke ovens) or process sources (e.g., open hearth furnaces, soaking pits) where the gas is used as fuel, and it will be accounted for in the emissions inventories of those sources. If the coke oven gas is desulfurized before burning, a Claus plant or a contact sulfuric acid plant will be used to convert the recovered hydrogen sulfide to elemental sulfur or sulfuric acid. Whichever may be used, the tail gas will constitute a SO_2 emission source that must be investigated as discussed above.

In addition to the principal noncombustion sources of SO_2, there are a variety of direct-fired processes in which SO_2 emissions can arise from the fuel burned or, possibly also in some instances, from the material being processed. Important examples are drying and calcining kilns and cement kilns. These sources are probably more important for their emissions of other pollutants, such as particulates and NO_x, than for their SO_2 emissions. Cement kilns, because of their high operating temperatures, are probably relatively important sources of NO_x, but there are few reliable data on their emissions of SO_2. Measurements of both NO_x and SO_2 emissions and their correlation with cement kiln operating conditions are particularly important because cement kilns are relatively large consumers of fuel.

Major point noncombustion sources of CO, actual or potential, are relatively rare. Catalytic cracking unit regenerators have been listed above because they are also sources of SO_2. The blast furnaces in steel mills are probably the only other important examples. Safety considerations alone normally dictate that blast furnace gas not used as fuel be burned in a flare before discharge to the atmosphere. Venting of some unburned gas from relief valves at the tops of blast furnaces does take place intermittently as the result of "slips" in the furnace that produce surges in gas pressure. However, the fraction of the total gas generated that is lost in this manner is relatively small under modern operating practices. The total gas generated is computed from the volume of air supplied to the furnace, and the amounts used as fuel or flared are commonly metered. The amount lost by venting during slips is obtained by difference. The average daily loss is thus obtainable with reasonable precision, although the actual releases are commonly of short duration--a matter of minutes. Establishing the actual hourly emission rates of CO from this source is probably impractical, but it is also unlikely that the amounts are large enough to seriously affect CO dispersion studies except possibly in the locality of a steel plant.

Apart from the types of point noncombustion sources of NO_x already mentioned, nitric acid plants constitute the major process source of NO_x. The NO_x concentrations in the tail gases are likely to be monitored continuously as a process control measure. If they are not, manual sampling and flow measurements must be used to develop a correlation between the NO_x emission and the measured production rate of nitric acid (or some other convenient operating variable).

The NEDS inventory data indicate that petroleum refineries constitute the major point process emission sources of hydrocarbon gases and vapors. A substantial amount of the total emissions from refineries is known to often result from a multiplicity of small leaks and vents, so that the source location is rather diffuse. Control of such emissions has been made difficult by the small sizes of many of the individual leaks. However, vaporization losses from storage tanks has been a large and specific source of hydrocarbon emissions. Losses from evaporation occur not only in refineries, but also in subsequent handling and storage of gasoline and other hydrocarbons liquids; estimates of such emissions should be made wherever possible.

Other point sources of emissions of hydrocarbons and hydrocarbon derivatives will include large surface coating operations, such as the spray painting of automobiles at assembly plants. Data will have to be developed on the actual consumption of coatings and solvent in these operations and on the rate of consumption. Even the operators may not currently have reliable data on anything but the gross long-term consumption.

Chemical analyses should be made to classify the hydrocarbons and hydrocarbon derivatives emitted according the major groups (paraffins, olefins, diolefins, aromatics, alcohols, ketones, and aldehydes). Where possible, the actual material vaporized, not the liquid stocks, should be sampled.

To summarize, Table 11 shows the major noncombustion sources and the basis of the principal pollutants emitted.

b. Area Sources

Combustion Sources--The stationary area sources are composed of:

- Residences.
- Commercial establishments.
- Institutional establishments (e.g., schools, hospitals, public buildings).
- Some small industrial (manufacturing) establishments.

Most of the pollutants arise from the combustion of fuels used for cooking, space and water heating, and steam generation. Some may come from combustion of wastes in small incinerators. Industrial establishments in this category are composed mostly of small manufacturing operations that employ fuels primarily for space heating or that burn small quantities of waste.

Table 11

MAJOR NONCOMBUSTION SOURCES OF POLLUTANTS

Pollutants	Sources
SO_2, SO_3	Contact sulfuric acid plants Claus sulfur plants Coke oven gas production Copper, lead, and zinc smelters Sulfonation of organic compounds
NO_x	Nitric acid plants Nitration of organic compounds
Particulate matter	BOF steel furnaces Secondary lead smelters Grey iron foundries Flour mills Cement plants Coke quenchers
Hydrocarbons and derivatives	Organic chemicals manufacture Paint and varnish manufacture Coating of fabrics with rubber or plastics Venting of storage tanks for petroleum products and organic chemicals

The rate of fuel consumption by the area combustion sources exhibits pronounced diurnal and seasonal variations as well as variations related to ambient temperatures. Fuel consumption peaks appear over periods of one to three hours. The consumption patterns of residences differ from those of commercial, institutional, and small industrial operations, which may operate at night and over weekends as well as during the day. The different types of sources may also use different kinds of fuel. Individual residences and small apartments tend to use natural gas, whereas large apartment houses and commercial, institutional, and industrial operations are relatively more likely to use oil or coal.

The amounts and nature of the emissions from fuel combustion are related not only to the type of fuel burned but also to the type and the size of the combustion equipment. If waste incineration is used, the practices employed in incineration may vary widely.

The only feasible way to develop an emission inventory for the area combustion sources is to apply emission factors characteristic of the combustion equipment to the quantities of fuels consumed. Unfortunately, there will seldom be data that will give directly the quantities of various fuels consumed by particular types of equipment and by specific types of users. The flow of natural gas to various sections of a city may be measured at metering stations. However, the measurements will indicate only the temporal pattern of the total flow to all users. Data on sales of oil and coal indicate only the average rates of consumption over relatively extended periods of time.

For significant area sources, it will be necessary to determine, by survey and experiment, the amounts and the patterns of fuel usage by typical components of area sources. For instance, the consumption of fuel by a typical apartment for cooking, water heating, and space heating could be measured and fitted to a model incorporating diurnal and seasonal influences and the effects of ambient temperature. Pollutant emission factors should be determined experimentally for the combustion devices unless they are already available. Similar determinations should be made for other representative source units: individual homes, offices or office buildings, retail stores, and such.

Noncombustion Sources--The most important noncombustion area sources are those that emit organic vapors and may make appreciable contributions to the total emission of hydrocarbons. Prime examples include vapors from (1) gasoline storage and handling by distributors and service stations, (2) dry cleaners, (3) painting, (4) degreasing, and (5) application of asphalt to roofing and pavement.

The total quantity of vapors released can be estimated fairly readily by applying appropriate emission factors to the quantity of gasoline handled, the amount of cleaning fluids consumed, the amount of paint applied, and so on. However, attainment of adequate spatial and temporal resolution will require a fairly extensive survey of the sources and a detailed study of operations at a representative sample of establishments or activities of each type.

The emissions of gasoline vapors from automobile service stations will vary with the day of the week and the hour of the day, as the volume of business fluctuates. The emissions of cleaning fluid vapors from dry-cleaning establishments are probably relatively constant during actual working hours. Solvent vapor emissions from the painting of products in small manufacturing establishments and from solvent degreasing operations should have a similar temporal pattern. However, the emissions of solvent vapors from the painting of buildings (interior and exterior) are irregular with respect to quantity, time, and the location of the activity. Nonmethane hydrocarbons are also emitted in significant quantities in summer daylight hours. (See Section VII.) Specific estimates for the Saint Louis area are needed before that contribution can be properly evaluated.

Again, for the major contributing sources of this type we recommend the direct approach to determining emissions data described later.

3. Mobile Sources

The determination of emissions from mobile sources presents special difficulties. The problem has received considerable attention in connection with air quality modeling specifically related to the nature and variability of traffic sources. In studies of this type (as described in detail in Section VII) a considerable degree of sophistication has been achieved in some cases. In these however, it has been convenient and appropriate to consider the relationships between the behavior of the sources and the ultimate air quality conditions in models which integrate and combine the various parameters involved in ways specific to the purpose for which the model is designed. In many respects, current modeling capability in this area is inadequate, and its improvement will be an important aspect of the RAPS program. The basic RAPS Emission Inventory may properly be expected to provide basic data for the use of such modeling development, and thus data on traffic flow and traffic links will be part of the data collected and stored. For the primary needs of the principle users of RAPS, however, the inventory must provide data on the emissions of the key pollutants from mobile sources, which contribute to overall input of emission data to air quality modeling or transformation process studies. Accordingly, we recommend that, until more refined inputs are available as a result of progress in mobile source emissions modeling studies, the basic traffic data be used with simple models based upon average speed to develop the initial information on emissions of the key pollutants.

F. Emission or Data Conversion Factors

The derivation of emission estimates from continuously monitored operating variables is a critical step that will determine the validity of the high resolution inventory data. Emission factors as currently used in developing emission inventories are generalized factors that are most valid when applied to a large number of sources or processes especially over extended time periods. They have limited applicability for use with single sources, certainly in the estimation of hourly emissions, and cannot therefore be used indiscriminately in deriving an inventory for RAPS in the manner proposed. The whole point of this inventory is to have high precision in terms of space and time, and for this reason, the best possible conversion factors must be used to develop the emissions data from the monitored variables. In general, this means that specific factors must be developed on an individual basis for each source for which the critical relationships are not already known with a high degree of confidence. (Even in the latter cases, some testing and verification would be desirable.) On the other hand, such specific source testing is a costly and time-consuming activity to be performed only when necessary. It is recommended, therefore, that consideration be given to using published, established emission factors for each source,* where the type of equipment or activity is sufficiently typical that the published emission factors can be identified as being truly representative of the case in question. It should be noted that, in general, the published factors have the most credibility for the major combustion sources (particularly in the case of SO_2 emissions). It is important to recognize, however, that in the case of the RAPS inventory, the role of minor sources is of great importance in local effect, i.e., at near-surface levels, with the spatial resolution required for RAPS. Lower confidence factors are assigned to emission factors for such lesser sources (quality factors B and lower in the categorization of Reference 11). Considerable caution must therefore be exercised in treating such lesser sources. This is especially the case for area sources, which, although minor contributors to the total burden, are important on the local scale. Special care is necssary to improve the accuracy of emission factors from such sources for use in refined modeling techniques.

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*For example, Reference 11.

G. Physical Aspects of Emission Sources

For purposes of dispersion modeling, it is essential to know not only the quantity of a pollutant emitted to the atmosphere but also the manner in which it is emitted. It is necessary to know the effective height from which the emitted pollutant can be assumed to start dispersing. Therefore, there must be sufficient information from which it will be possible to estimate the effective height of the plume of gas. The effective height of the plume is the sum of the physical height of the stack and of the plume rise, which is the distance that the plume ascends under the influence of its initial momentum and its buoyancy.

For small source units, such as those that constitute area sources, the water gases are usually discharged effectively at ground level. Even where the gases are discharged a short distance above the roof of a building, they will generally be carried quickly down to ground level. Hence, it is commonly assumed in dispersion modeling that the waste gases are discharged at ground level and that neither their initial temperature nor velocity influences subsequent dispersion.

For point sources, and particularly for the larger ones, the emission inventory data must be supplemented by data on the gas flow rate, temperature, pressure, and specific gravity, and on the physical height and diameter of the stack. Calculations of the plume rise require knowledge of the gas exit velocity and the stack inside diameter at the plane of discharge, and of the temperature and specific gravity of the gas. Calculation of the specific gravity of the gas requires knowledge of the composition of the gas stream including the amount of water vapor.

In addition to the data noted above, the inventory should include information on the layout of the source stack with respect to other structures. As a rule of thumb, a stack should be at least 2.5 times the height of the nearest structure; otherwise, the proximity of the other structure may lead to "downwash" of the gas from the stack and a consequent rapid descent of the plume to the ground. Short stacks projecting from the roof of a building are particularly subject to this kind of problem, and the role of the stack in securing dilution and dispersion of the gas is largely lost.

H. Units of Measurement

Many agencies continue to use English engineering units, and it is virtually certain that many of the data coming into the inventory will continue to be expressed in engineering units despite a growing preference for the metric system. It is undesirable to convert such data into metric units manually before storage in the inventory because of the large amount of time it would take plus the time required for checking for conversion errors.

It is recommended that the data be entered into computer storage in the same units in which they are originally received. The computer should then be programmed to convert the data to metric units when they are recalled and printed out. This procedure will diminish the amount of manual processing that the data must undergo and still retain flexibility.

I. Specification of the RAPS Emission Inventory

1. General

While NEDS as a source of information on annual or long-term emissions from a broad range of pollutants, it is recommended that a special high resolution RAPS Emission Inventory be developed to provide hourly data emissions of SO_2, CO, NO_x, and HC in the form of direct statements of weight of pollutant emitted in kilograms each hour from each point or line source or area element, for the Saint Louis (AQCR). Locational data will be provided in UTM coordinates with a resolution of at least 0.1 kilometers for point sources. Mobile sources will be specified in terms of traffic links (with a resolution of approximately 0.02 kilometers) for major routes and of areas for secondary routes. Both for stationary and mobile sources, the area elements will reflect either the spatial resolution of the basic data from which the emissions are estimated (e.g., housing developments) or one kilometer grid squares, whichever is the smaller.

Information on the physical characteristics of point sources and the prime data used in compiling the inventory would also be provided. Although it is not considered practicable to develop comparable data for particulates, it is recommended that additional data on particulate emissions be collected to supplement the NEDS inventory, specifically data to distinguish between coarse and fine particulate emissions from the major sources.

For initial planning purposes we propose that only point sources emitting over 100 tons per year of each pollutant be considered individually. The estimation of emissions from such sources will be accomplished in classes according to the magnitude of each source as specified in detail below. We recommend that emissions data be based upon direct monitoring of emissions for the largest sources. For other major sources, direct monitoring of hourly fuel consumption operating or process data should be used as the basis for estimating emissions. For smaller point sources, we propose that emissions be estimated on the basis of generalized patterns of temporal variation of emission as a function of source type and using the best available data on fuel consumption, operating or process data (i.e., per shift, daily, weekly). In the limit, this approach approximates current practice in which annual totals of such data are used as a basis for modeling. For area sources, we recommend the use of modifications and adaptions of already available emission models. Similarly, for a first approach to assessing mobile course emissions, we recommend the use of available models. Improved mobile source models should be employed as they become available to provide higher quality data. A simple new model should be developed to estimate natural emissions of nonmethane hydrocarbons on summer days. In all cases, we propose that special testing efforts be carried out to ensure that the emission and conversion factors used to derive the emission estimates are as reliable as possible and have regard for the high temporal resolution required. Standard emission factors should be employed only if a review of the source on a case-by-case basis indicates that such a factor may be used with confidence in the particular case.

2. Point Sources

a. Classification by Size

It is convenient to classify point sources by size according to the amount of pollutant emitted annually.

- Class I, over 100,000 tons per year.
- Class II, over 10,000 but less than 100,000 tons per year.
- Class III, over 5,000 but less than 10,000 tons per year.
- Class IV, over 1,000 but less than 5,000 tons per year.
- Class V, over 100 but less than 1,000 tons per year.
- Class VI, over 1 but less than 100 tons per year.

The numbers of sources comprising these classes for SO_2, CO, NO_x, and HC and their contribution to the total burden in each case is shown in

Table 12 based upon NEDS data that is discussed in greater detail in Section VI.

As indicated by these classifications, a relatively few sources account for the bulk of the emissions.

The annual emissions, obtained from the NEDS inventory, although adequate for initial source classification, are not entirely representative of the probable contribution of the various sources to air quality at specific time periods. For example, units supplying steam for space heating will be operated only in periods of cold weather, and the actual emissions at that time will be higher than indicated by the annual average. Furthermore, the emission rate will follow a diurnal cycle even within a single day.

The foregoing considerations are important because reports from atmospheric dispersion studies have indicated that ground-level pollutant concentrations are disproportionately affected by local low-level pollutant emissions, even though the latter are individually small and contribute--individually or even collectively--only a minor percentage of the total pollutant emission from all sources. Thus, the smaller emission sources cannot be ignored even as part of the general RAPS inventory that is intended to supply emission estimates for use in mesoscale atmospheric dispersion models. They must be appropriately evaluated even though the effort required is more than proportionate to their relative contribution to the total emission. Within these reservations, the statistics noted in Table 13 provide a useful basis for assessing the general magnitude of the problems involved in developing a program of point source emission estimates and describing the approach recommended.

b. Data Acquisition Groups

We propose that point source emission data be derived in four broad groups according to the basic records used to estimate emissions.

Group I. Continuous emissions monitoring records

Group II. Continuous records of fuel consumption, operating, or process data

Group III. Short term, periodic records of fuel consumption, operating, or process data (per shift, day, or week)

Table 12

POLLUTANT SOURCES BY CLASS

Source Strength (tons per year)	SO_2				NO_x					CO				HC			
	Number of Sources	Cumulative Number of Sources	Percent of Total Emission	Cumulative Percent of Total Emission	Number of Sources	Cumulative Number of Sources	Percent of Total Emission	Cumulative Percent of Total Emission	Number of Sources Not Emitting SO_2	Number of Sources	Cumulative Number of Sources	Percent of Total Emission	Cumulative Percent of Total Emission	Number of Sources	Cumulative Number of Sources	Percent of Total Emission	Cumulative Percent of Total Emission
Class I (>100,000)	4	4	49.8	49.8						1	1	79.5	79.5				
Class II (10,000-100,000)	9	13	31.3	81.1	7	7	52	52		5	6	19.1	98.6				
Class III (5,000-10,000)	13	26	5.7	86.8	3	10	6	58		5	11	0.8	99.4				
Class IV (1,000-5,000)	41	67	7.0	93.8	14	24	8	66	4					23	23	58.7	58.7
Class V (100-1,000)	117	184	3.1	96.9	87	111	8.3	74.3	20	20	31	0.1	99.8	76	99	32.0	90.7
Class VI (1-100)	174	358	3.1	100	369	480	25.7	100	195	185	216	0.2	100.0	371	170	9.3	100

Table 13

TENTATIVE WORKLOAD* FOR THE MONITORING OF SO_2 AND NO_x SOURCES

Group	Origin of Data	Number of Sources	Test Program		Cumulative Percent of Total Emissions	
			Percent of Sources Tested	Number of Sources Tested	SO_2	NO_x
Group I						
Continuous emission monitoring	Class I and II sources	13	75%	10	81	52
Group II						
Continuous fuel consumption, operating or process data monitoring	Class III sources Individual tests (8) Sample tests (3)	13	80	11	87	58
Group III						
Short-term fuel consumption operating or process data monitoring	Class IV sources (45) Individual tests (24) Sample tests (5)				94	66
	Approximately 20% of Class V (30) Individual tests (10) Sample tests (5)	75	59	44	95	70
		—	—	—	—	—
Total		101	65	65	95	70

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*Based on estimates of testing program from Table 12 data.

Group IV. Long-term (semiannual or annual) records or estimates of fuel consumption, operating, or process data.

Within Groups II and III, a further distinction should be made between sources for which separate conversion or emission factors are established and those for which representative factors will be established. Data from Groups I, II, and III will be collected on an ongoing basis.

In principle, it would be desirable to deal with all sources under Group I. In practice, sources should be treated in the highest ranking group possible while maintaining regard for the costs and difficulties of so doing. A tentative work load is indicated in Table 13 for SO_2 and NO_x sources to show how the scope of effort can be analyzed and assessed. This shows that, by collecting data routinely from some 101 sources (of which 65 have been individually tested), approximately 95 percent of the hourly SO_2 emissions and 70 percent of the hourly NO_x emissions can be estimated on a direct basis. Similarly, over 90 percent of the emissions of CO sources can be estimated on an hourly basis by the treatment of direct data from only six sources. Still, it would be necessary to obtain data from and test some 10 or more sources to achieve hourly estimates from direct data for only 50 percent of the HC emissions.

It is recommended that the method of grouping sources for this purpose be determined after a survey has been made of all the sources over 100 tons per year. This survey will produce a better understanding of the data available and the difficulty of collecting useful direct data on fuel consumption or operating or process data from which hourly emissions may be derived. Such a survey should preferably be made in site visits to obtain more details of the source and operations than are available from the NEDS review. It should ascertain the availability of direct monitoring data on emissions or fuel consumption and of operating or process data that can provide direct information on hourly emissions. Alternatively it should reveal the nature of short-term data from which hourly emission estimates can be derived. The survey should pay particular attention to the form of the available records, and the optimum frequency and method of collecting them.

The survey will provide a basis for determining how much special source testing is necessary to provide reliable conversion or emission factors for individual sources and possible categories of source. This survey would also reveal the needs and opportunities for installing appropriate monitoring devices at selected sources, an approach that could usefully upgrade the inputs from certain sources and reduce data collection effort.

It will be appreciated that the methodology proposed allows considerable flexibility in the manner in which sources are treated. In this way, optimum benefit may be derived from the available RAPS inventory budget on a case-by-case basis. In any limitation of effort for budgetary reasons, it would be preferable to reduce the numbers of sources treated individually, rather than to restrict the source testing program, since operating patterns may be more confidently determinable at the present time than emissions or conversion factors.

3. Point Combustion Sources

Combustion point sources burning oil and coal are responsible for most of the SO_2 emissions in the region, and are also major sources of NO_x. Those burning natural gas produce NO_x, but do not produce SO_2. Neither type of point source is a major source of CO or HC, particularly when compared with automotive sources, but their emissions of these pollutants are significant and must be considered in the context of RAPS.

The procedure for collecting emission data within the groups described in Table 13 is described here.

For each source, appropriate reference data, such as type of unit, nominal ratings, control equipment, and so forth, together with physical characteristics of the emissions point (i.e., stack height, diameter at the discharge, location of stack in UTM coordinates) must be compiled. In addition, critical fuel consumption, operating, or process data must be acquired in routine collections. These constitute data as a function of time, ascertained in the initial survey to be basic for the determination of emissions.

Typical of such data are

- Type of fuel (e.g., coal, oil, natural gas).
- Characteristics of fuel (e.g., sulfur and ash contents, higher heating value).
- Fuel-firing rate (e.g., weight or volume rate, thermal rate if available).
- For boiler furnaces, the steam generation rate at specified temperature and pressure.
- For power boiler furnaces, the steam generation rate and electric power output.

Then, the following procedures should be applied.

Group I: Directly Monitored Emission Sources--Most of the sources in Class I (over 10,000 tons per year of pollutants) are expected to be equipped with continuous monitoring devices for the measurement of SO_2 and NO_x and possibly with a Pitot element to measure flue gas flow continuously. Exit flue gas temperatures are likely to be recorded continuously at such large sources. The calibration of the permanently installed recorders will have to be verified experimentally unless data on such verification are available at the source. Similarly, flow measurements have to be obtained or verified. If no permanently installed Pitot element is on hand, such flow measurements will have to be correlated with a measured furnace operating parameter or variable. It may be advantageous to undertake the determination of other pollutants at the time of calibration. For example, from flue gas analysis, measurements of CO and hydrocarbons should be made, if the source is a significant (more than 100 tons per year) emitter of these pollutants.

Group II: Directly Monitored Fuel Consumption, Process, or Operating Data--Typically these are sources emitting less than 10,000 tons per year of SO_2 or NO_x but more than 5,000 tons per year and any larger sources not equipped with continuous monitoring devices. These units are not expected to have continuous monitoring systems for measurements of pollutant concentrations, but they should have good records of fuel consumption or other operating data with hourly resolution. In Group IIA, conversion factors are derived linking the continuously monitored parameter with the emission rates are derived from manual sampling at each source. This is carried out initially in the program and thereafter repeated intermittently to ensure the continuing validity of the results. In Group IIB, standard emission factors may be assigned to categories of similar sources after they are determined by testing representative stacks.

Group III: Short-Term, Measured Fuel Consumption, Processing, or Operating Data Available--In this group, in which both Class IV (1,000 to 5,000 tons per year) and Class V (100 to 1,000 tons per year) sources will be treated, records will be available on a shift, daily, or weekly basis for fuel consumption, process, or operating data. (Direct hourly data must be interpolated.) Again two possibilities are open. In Group IIIA, each plant is considered individually, and tests are made to establish both the time dependence and the amount of pollutant emissions that can be deduced from the recorded data. Appropriate conversion or emission factors are thus assigned to each source tested. In Group IIIB, factors are established for appropriate categories of similar sources on the basis of tests of representative samples.

Group IV: Long-Term Fuel Consumption, Processing, or Operating Data--For sources over 100 tons per year, for which suitable specific data are not available (or which must be treated in this fashion for budgetary reasons), we recommend the use of modeling procedures of the type described in Section VII. A suggested approach for SO_2 is to employ the Argonne[2] model, and for NO_x and HC the SAI model,[1,3] but with adaptation and modification to ensure that the best possible input data on fuel consumption are used and that conversion factors are verified by testing.

4. Point Noncombustion Sources

Because of the extreme diversity in point noncombustion sources, no general and detailed procedure for correlating emissions with source operating variables can be offered; appropriate procedures will have to be worked out, case by case, for each type of source, following the general principles outlined in Table 13 and in Section IV-E-2.

For the purpose of organizing the inventory, such sources should also be considered according to the most important pollutant that they emit. In this grouping, particulate emissions will not be used as a basis even though they may be the principal pollutant emitted by some sources.

J. Stationary Area Sources

1. General

Stationary area sources contribute minor proportions of the total burden of SO_2, NO_x, CO, or HC as described here. Their importance may be significant, however, in the context of RAPS, since they may contribute significantly to the concentrations of the key pollutants at the near-surface level on a local basis.

2. Area Combustion Sources

The NEDS inventory data indicate broadly that the emission sources in this category are primarily those using natural gas or distillate oils. Consequently, the estimated SO_2 emissions are minor (only about 1 percent of the estimated total). The relative contribution of NO_x from these sources is greater, but still a minor part of the total. The NEDS inventory indicates that 28 percent of the total NO_x emitted comes from area sources, but these include vehicles that are known to be, in the aggregate, a large contributor. The contributions of CO and hydrocarbons from the stationary area combustion sources are likely to be minimal.

As discussed, the only practical way to estimate short-term emission rates from the area sources is the use of simulation techniques such as are discussed in Section VII. The two most advanced models to date are the Argonne model[2] for SO_2 and the SAI model[1,3] for CO and NO_x. They are alone in their class in that they have received significant field verification. As discussed in Section VII, the models have limited precision for the estimation of area combustion source emissions for the RAPS inventory. Accordingly, it is suggested that to improve emissions estimates by such modeling techniques, more accurate and precise survey data on fuel consumptions as well as more accurate emission factors be obtained. Both will require that new experimental studies be made at typical sources.

Data on fuel consumptions in specific, small areas of cities are not readily available. Commonly, continuous metering of natural gas is carried on only at a few points on lines supplying major sections of the city. The flows metered at these points give no indication of the breakdown of usage by type of source, and the temporal variations in flow reflect only the summation of the demand patterns of different users. The consumption of gas by individual customers can, of course, be obtained from meter records. However, these will, at best, give only the monthly totals of gas consumed; they will not show the different uses by a given customer.

Data on fuel oil consumption by residential and commercial users are largely restricted to data on fuel oil sales. Even users will generally have no more than a qualitative idea of the actual rates of consumption over short periods.

To obtain a high degree of both temporal and spatial resolution in the estimates of emissions from area sources, it will be necessary to conduct extensive surveys of the patterns and amounts of fuel usage by representative sources. Sufficient sources must be surveyed to constitute statistically valid samples. It will probably be necessary to install meters at these sources that will record both the rates of fuel consumption at various times and the integrated total.

Residential and commercial installations, in particular, will show marked diurnal variations in their fuel consumption patterns as well as variations in usage between week days and weekends or holidays. There will also be seasonal variations in the magnitude and distribution of fuel consumption. For example, the consumption of fuel for water heating may be relatively constant throughout the year, but the consumption for space heating will be highly seasonal. Because space heating will be the most highly variable as well as the largest consumer of fuel, the rate of fuel, consumption for this purpose should be correlated with ambient temperature.

Better emission factors must be obtained for the typical fuel-burning units used in residences and commercial establishments. Some required data may be derived from other studies currently in progress, but others will probably have to be made specifically to meet the needs of the RAPS inventory.

Once emissions are determined for the representative sources, the emissions from specific areas can be estimated from the number and sizes of residences and commercial establishments in the areas.

3. Area Noncombustion Sources

The only area noncombustion emission sources that appear to be significant are those emitting hydrocarbons and hydrocarbon derivatives (gasoline and solvents). The nature of the sources and their emissions was already discussed.

The release of solvent vapors from the painting of buildings probably cannot be incorporated in a practical way into models for prediction of hourly emission rates; the emissions are too irregular in quantity, time, and location. Probably also, the solvent emissions from this source are too small to be of concern in mesoscale dispersion studies. However, a painting operation might be of concern to a microscale dispersion study being conducted nearby. If so, making allowances for the emission is best handled as a project task of the dispersion study.

The area hydrocarbon sources of consistent importance will consist primarily of the smaller gasoline service stations and dry cleaning establishments. It will be necessary to survey the typical operating cycles of such establishments to establish the pattern of their emissions.

K. Mobile Source Procedures

For automotive mobile sources, we recommend that an average route speed model with a link or line source geometry supplemented with measured data of traffic flow (via fixed sensors on high volume freeways and selected arterials) be used.

The SAI (Systems Applications, Inc.) model[1,3] for hourly CO, NO_x, and HC emissions is recommended. It can have modified inputs derived from Stanford Research Institute's model[4] for spatial and temporal distribution of vehicle number and speed on a link basis for primary traffic and area basis for secondary traffic. As a basis for this approach, data should be assembled on traffic volumn and the location of the primary traffic links and of the areas of secondary traffic. Additionally, arrangements should be made to install and collect data from fixed sensors on selected routes, as noted above.

As soon as improved methodology is developed for refining the inputs to such models, it should be used to update the inventory, and, in due course, the simple average speed approach could be replaced by more comprehensive modeling techniques as they become available.

In any case, prime data relating to route links and such would be available from the RAPS Emission Inventory records for use in such model development or other purposes.

For other mobile sources the following models should be used to the extent possible:

- Geomet model[5] for diurnal emissions from river vessels and railroads.
- Northern Research and Engineering Model,[6] as revised by Geomet (in preparation), for aircraft emissions.

L. Natural Background Emissions

Techniques of estimating the natural emissions of nonmethane hydrocarbons in summer daytime should be developed so that such emissions may be added to the inventory in time for studies in which hydrocarbon emissions are considered.

M. Particulates

As noted, it is impracticable to develop a high resolution inventory of particulate emissions on a routine basis. For modeling studies it would appear that such emissions must be treated on a project basis with special collections of data (possibly limited in space and time) as required. In addition, it is suggested that the tracer technique be employed to investigate the dispersion of particulates under various conditions.

N. Scheduling and Scale of Effort

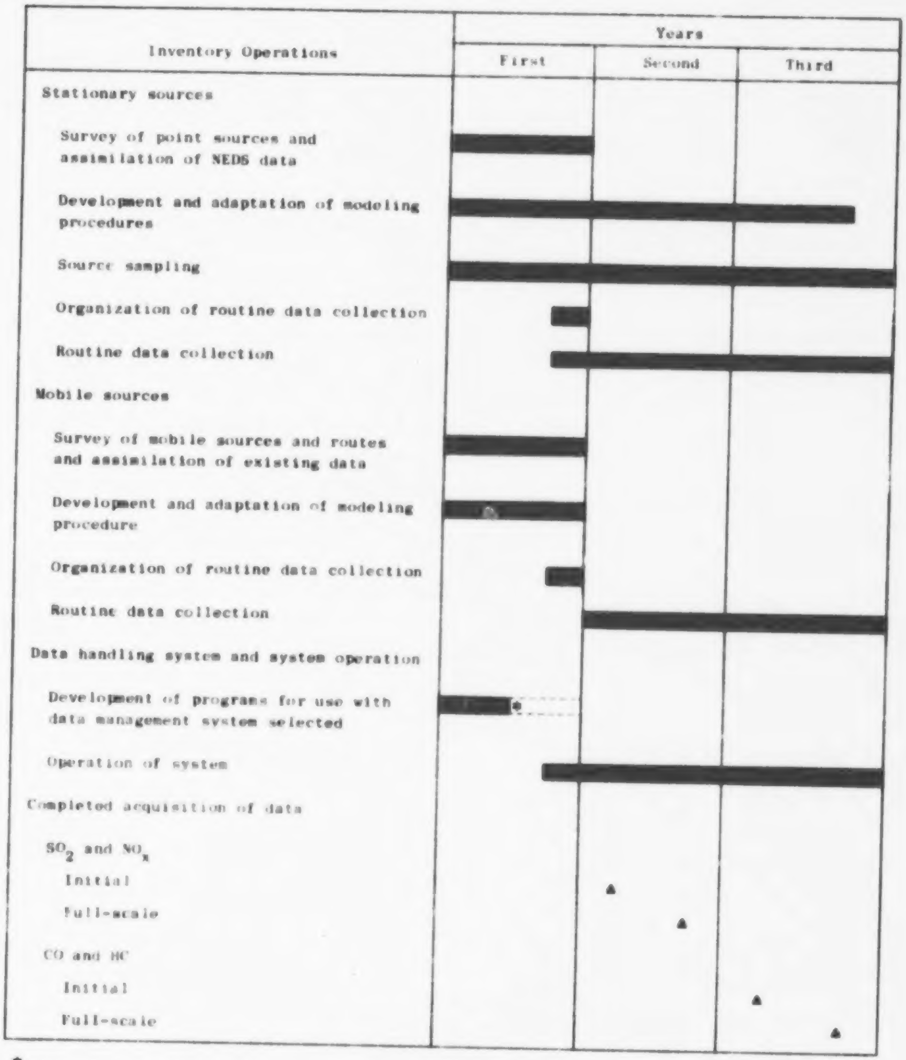
The development of a complete RAPS Emission Inventory is scheduled to take up to three years.

It would be desirable, however, to aim for an earlier provision of emissions data, especially for the first critical tests of air quality and dispersion models. These will use SO_2 (emphasizing stationary sources). Accordingly, the development of the inventory of these pollutants should be given priority, particularly in the source testing and modeling phases. (Since the majority of point sources of SO_2 also emit NO_x, the collection of data on this pollutant can conveniently be carried on in parallel.)

A possible schedule is shown in Table 14. The aim is to provide initial data on SO_2 and NO_x by the first quarter of the second year of full activities and complete data by the end of the third quarter of the second year. For CO and HC, effective initial data should become available by the end of the second year and complete data by the third quarter of that year.

Table 14

DEVELOPMENT SCHEDULE



Inventory Operations	Years		
	First	Second	Third
Stationary sources			
Survey of point sources and assimilation of NEDS data	■		
Development and adaptation of modeling procedures	■	■	■
Source sampling	■	■	■
Organization of routine data collection	■		
Routine data collection	■	■	■
Mobile sources			
Survey of mobile sources and routes and assimilation of existing data	■		
Development and adaptation of modeling procedure	■		
Organization of routine data collection	■		
Routine data collection		■	■
Data handling system and system operation			
Development of programs for use with data management system selected	■ *		
Operation of system	■	■	■
Completed acquisition of data			
SO_2 and NO_x			
Initial		▲	
Full-scale		▲	
CO and HC			
Initial			▲
Full-scale			▲

*Additional effort if interface facilities of basic system need major extension.

V. TASK C: EMISSION INVENTORY FILE SYSTEM

A. General

This section concerns the specifications for data formats in the emission inventory. Because this inventory is intended primarily for air quality modeling in the RAPS program, the data elements were chosen to provide input data and supplementary documentation for that purpose.

The data structures specified below are extensible data items in a data reference system that provides the facilities to manage such data types. Data systems of this kind have been developed and are available. We describe in this report the main functional features of the inventory system, and the computer system interfaces needed to provide data to modeling programs.

Although most of the expected categories of data are used to demonstrate the data structures and formats, this chapter is not intended to be a complete listing of the content of the emission inventory. Because the data structures are specified to be extensible, any data not explicitly shown can be attached to the structure.

Section B describes the computer system environment in which we are assuming this inventory will be implemented. Section C discusses the main operational aspects of the inventory. Both of these discussions provide the basis for the design of the data structures described in detail in Section D. Section E suggests a possible alternative format for implementing these data structures in the absence of a supporting data reference system. Section F lists the steps required for implementation of the inventory system, and Section G is a tabulation of the principal specifications of the computer programs needed.

B. System Environment

In this section, we discuss the key features of the system and software environment in which the emission inventory will be implemented. A data management system will be needed for the operation of the RAPS Emission Inventory, although it may be possible to perform the inventory operations with systems not having exactly the features described here. Data management software is usually the responsibility of the central computing group of an organization, however, because this system must meet the needs of the Air Data Branch for the inventory functions, specifications for the system are given in this report.

Either a general-purpose or a custom-designed data management software system must be obtained or constructed that will run on the computer facility at EPA-RTCC. This data management system should provide the basic functions of file definition; addition, revision, and deletion of data items; retrieval of selected items using selection criteria on data content; hierarchic sorting by content; and output of specified data components of selected items in specified formats to construct files for use in other programs.

The system should provide for defining hierarchically structured data items, with components consisting either of single data records or lists of records, subordinate to other components of the data item. We assume that the system will provide means for assigning names to each of the components of a data item. The system should provide functional records of any desired length to contain character strings.

The system should provide for data entry from punch cards, tapes, and terminals (if it functions in an on-line or interactive mode). It should also provide for merging of preliminary files from disk. Data should be readable as ASCII character strings. Conversion of declared numeric data to numeric internal representation may be provided, but is not necessary. The system should not pad card input with blanks and should provide for continuation of a data record to successive cards until the record is terminated by an end-of-record character.

For the purpose of this emission inventory, all operations can be carried out in batch operating mode. However, the RAPS Data Manager has indicated that the RAPS program will have other data base requirements, and that compatibility among these different data bases would be operationally and economically beneficial. One level of compatibility that can be obtained is to use the same data management software to implement all of the RAPS data bases. Some of the data base applications may require on-line use of the data system for retrieval and perhaps even for data entry. Therefore, it would be desirable for the data management system to have the potential capability of being used in an on-line mode, perhaps by means of additional software options.

All of the presently existing air quality models are written in Fortran. The primary purpose of the emission inventory file is to provide input data to these models. Therefore, a system that has an interface for Fortran programs would be advantageous, because the input data files could be constructed by means of Fortran programs that could access the inventory files through the system interface and write data in the formats and data representations required by the models. Since the inventory file formats include data embedded in character strings, using various separator and operator characters, these records must be decomposed by the Fortran interface programs, the numerical values extracted as character strings, and converted by the interface into proper internal number representation for arithmetic operations. This translation of the internal formats will have to be added to any interface routines that a data management system may already have.

The RAPS Data Manager has stated that EPA-RTCC will obtain the Univac DMS-1100 data management system when their Univac 1100 computer is installed. DMS-1100 is described in a catalog as a host language system: it is based on Cobol and can be utilized only by Cobol programs that issue calls to the data management system for file operations. DMS-1100 is not in itself a complete data management system. It must be implemented by writing Cobol programs to perform the functions of defining and labeling data structures, entering data, sorting and indexing, and formatting output data. There is no Fortran interface to DMS-1100, so additional system programming work would be needed to provide a facility for generating input files to models if the inventory is based on DMS-1100. (DMS-2000 is also being acquired.)

At this time we do not have sufficiently detailed information about the facilities and file structures provided by DMS-1100 to be able to make any positive recommendation concerning its applicability to the RAPS Emission Inventory.

It is estimated in Section IV on Task B that the total number of point sources that should be included in the RAPS inventory will probably not exceed 1000. The number of area sources will depend on how the areas are defined. If each area is only 1 square kilometer, then there may be several thousand area sources to be described. However, the format described here allows for any size and shape of area source and also for including sets of equivalent area sources in one item, so the number of inventory items needed to describe the area sources can be reduced to a few hundred if this feature is used. The line sources that need to be described will be mostly major traffic routes, and they should be relatively few in number.

For the purpose of specifying the capacity requirements of a data management system for the RAPS inventory, we can probably put an upper bound of about 2000 data items per file. For some point sources, the data elements may be fairly detailed, but most source items will describe only one or two products or pollutants, and only a few typical patterns of time dependence can be predicted by emission models, so that most of the data items will contain from 200 to 500 characters for a total of about one million characters. The longest elements in the file will be the hourly data on consumption and emission for about 50 point sources, each of which will require up to 75,000 characters to describe hourly consumption to 1% precision for a year. Then, if hourly emission values are also stored for an average of three pollutants for each such source, the total size of each of these point source items will be about 300,000 characters, or 15 million characters for 50 sources.

The master inventory files will be easily accomodated on a single large disk pack, such as the IBM 3330, or the Univac Fastrand drum, which holds over 100 million characters per drum. Therefore, the storage of emission values in the inventory file will not significantly affect the computer facility requirements.

The accumulation of historical inventory data, over a period of years, will most conveniently be accomplished by making a separate file for each calendar year with the possible exception of the first one, which will have to average several prior years experience. If this system is eventually extended to maintain emission inventories for other regions, each Air Quality Control Region (AQCR) should be handled as a separate set of data files.

C. Inventory Operations

To define the data formats for a system file, it is necessary to have a view of how the file will be used as a part of an overall system operation. In the case of this emission inventory, there are three major operational activities: source data preparation and entry, computation of emission values of sources and production of data file inputs to air quality model programs.

A principle we have followed in designing these data formats is that source data should be organized and filed with a minimum of manual transformations from the form in which it is gathered to the form in which it is entered into the computer. Thus we have chosen to organize the file with sources as the primary items, and we are making provision for entering the names of fuels, pollutants, and other materials in readable standard nomenclature. Consumption data should be entered in the units in which it is normally described to avoid manual computations and errors. The emission modelling programs can compute emission values in standard system units.

The SAROAD parameter coding manual of EPA has assigned integer code numbers to many hundreds of compounds of interest in air pollution. However, only a relatively few pollutants will be included in the high resolution emission inventory for air quality model verification. Furthermore, the SAROAD codes do not include materials other than air pollutants, such as consumables that will be included in the emission inventory as a basis for computing emissions. Finally, writing 'SO2' instead of '42401' to describe sulfur dioxide is more brief, more readable, requires no catalog look-up by an inspector or data clerk, and is far less error prone.

We suggest, in this report, that compounds and other materials be labeled mnemonically and concisely. Of course, it is essential that the labels be absolutely consistent. Since the number of materials is expected to be relatively small, a standard thesaurus of material identifiers should be easily maintained.

A considerable amount of data is needed to identify and describe each source in addition to the set of values for emission or consumption of a variety of possible pollutants or materials and a specification of the time dependence of those values. The number of different kinds of sources and different materials indicates that a hierarchic list type of data structure is most applicable to this purpose.

In connection with model sensitivity studies or studies of control strategies, it will be desirable to be able to include the effects of simulated sources, or real sources operating under simulated conditions or under actual but very unusual conditions. All such sources can be entered into the Master Inventory in the standard way, but identified by an appropriate category name so that they can be selectively included with or substituted for real sources in data files for model runs.

It is expected that most of the data will be entered in a batch mode via punched cards or using key-to-tape machines. In either case, the hierarchic structure of the data items must be represented in the character stream by additional delimiter characters. An extended format for this purpose is described in Section E on extensions for batch data entry; however, any existing system will have its own format for batch entry. This format is sufficiently complicated that it is recommended that the data be written by a skilled data clerk, who can transcribe original data from an inspector's notes or from data collection forms. This clerk should also be qualified to proof read data entries both for syntactic correctness and for data sense. Data preparation forms can be used to aid in the structuring of the data and to make it easier to use the correct syntax and punctuation characters. However, it is not possible to depend only on well-designed data preparation forms for data quality, because the content as well as the form of the data must be verified.

A data management system generally will check its own data entry syntax, and should be used for this purpose. However, the internal formats of some of the data elements, such as consumption data, will be transparent to the system and will need to be tested by a separate emission inventory verification program. The same program should also verify whether material names are included in the material name thesaurus. This thesaurus therefore should be kept in the form of a computer reference file available to the data entry program as well as in paper reference copies in the data preparation rooms. For example, the substitution of the digit-'0' for the letter-'O' in SO2 by a typist can be detected this way. The same kind of verification should be applied to all other data descriptors for which there is only a small number of correct choices. The verification program should make output listings of all items in which it detects errors in a form in which the erroneous data component or syntax is identified. Although the verification program could include facilities for user-entered corrections, it will be more practical to use the editing facilities of the data management system for this purpose, and this is recommended as the preferred approach.

Data should be entered first into a preliminary data system file, so that they can more easily be further verified by printing out the entire content of a small data set in an expanded easily readable format for proof reading and further correction prior to adding these items to the main inventory file. Another reason for this preliminary stage is that most data management systems perform a significant amount of behind-the-scenes processing on new entries into a directly accessible file, such as building address tables, hash coding computations, making inverted lists of key data elements. The small preliminary file, on the other hand, can be a simple sequential file with none of this extra processing until after the data manager has determined that it is accurate enough to merge it into the main file.

The retrieval facility of the data management system will be used for the selection of groups of sources for which emission values can be computed by the same model or are selected for production of a particular data file for model validation or for editing and updating of selected items. The recrieval of source items should be accomplished on the basis of any appropriate data in the item, such as source category, pollutant, location, or status of previous computation of emissions.

The retrieval facility can also be used to produce special files organized in terms of any user-specified parameters, such as a pollutant, sources using fuel at greater than some rate, location. This can provide for a variety of special applications without requiring additional file programming. A sorting capability in the data management system should be provided to order and index these files by their content.

In very few cases will source data include measured values of emission. For most actual sources, the emission must be calculated from consumption or other source data. Formats are provided in this inventory for both emission data and consumption data, using the same data syntax and structure for both. For those sources for which there are no direct emission data, emission must be calculated using emission factors or emission models applied to consumption or activity data. The emission factors have been compiled by EPA into a table as a function of the Source Classification Codes (SCC) for a wide variety of industrial processes and consumables.

After a set of new data source items has been entered, the next logical operation is to calculate the emission values for those sources that have no pollutant data entered. The results of these computations can be appended to each source item as the content of a pollutant component using the same time interval description for each source as was used for consumption if only the emission factor is applied. If a specific emission model is used, the time interval description also must be generated by the model program.

The emission inventory software system will require emission model programs that can access the consumption data element for each item, refer to the SCC code for that material, look up the appropriate emission factor in an auxiliary Emission Factor File maintained as a direct access file on the system, and compute the emission values for each of a prespecified set of pollutants. If the programs have access to the data system for file writing as well as reading, they can then update each item by adding a pollutant list component with an entry for each pollutant to be calculated. One of these will be a "no model" program that will only multiply consumption data by emission factors to obtain emission values. These emission models will generally also require input of ambient atmospheric data, which can be obtained from meteorological data files based on the RAPS data network. These files are not considered in this report, because they are not part of the Emission Inventory system.

In this manner, the master emission inventory file will serve both as a file of input source data and also as the repository for derived emission values with no duplication of source information.

For the principal objective of the RAPS program the final function is that of production of input data files for air quality models. In general, the required emission data will be that for a specified pollutant for a specified time interval or series of time intervals and also for specified positional coordinates. Many data management systems have search and retrieval features for selecting data items that satisfy specified data constraints or specifications. Some preliminary selections may be made using the system facilities, such as selection of a particular type of source, certain UTM coordinate ranges, and the like. However, the time dependence data are coded in the emission data element format in a special way, and a general system feature will not be able to decode it.

If the general data management system includes the capability for calling procedural language subroutines, such a subroutine can be written to decode the time and emission data in the emission data element and can be linked to the data system so that it will automatically be invoked whenever the system is asked to search for emission data within some particular time range. If that capability is not available, then the data file production program must have a subroutine included within it to perform the time interval selection function.

After the items containing the desired data have been identified, it is necessary to abstract the emission data for the particular pollutant and write an input data file for the model program. The input file must be written in exactly the format expected by the model; the values must be in the units defined for that model program. Since the model programs are written in Fortran, the data file must also be written with the appropriate integer or floating point representation for each quantity.

The generation of these input data files will require interface programs designed to perform this task. These programs (or maybe one general-purpose file-building program) must read the emission data elements that are character-string data, decode them, compute new time sequences if the model requires them, transform the string representation of the emission value to internal numeric form, read the name of the unit used and multiply the values by the proper conversion factor, and write the file for the model.

Most of the air quality models operate on the basis of allocation of emission values to a fixed geographical grid system. The data interface programs will also have the function of translating the geographical coordinates of point, area, and line sources in the inventory into the appropriate grid units for the model.

The data file derived from the RAPS Emission Inventory can be combined with similar data files derived from other source inventories, such as NEDS, to obtain the most economical use of existing systems. It is assumed that programs to generate input data files for atmospheric models already exist in the NEDS system. If such programs do not exist, then it may be more economical to transfer all the NEDS data relating to the RAPS area into this RAPS inventory system.

The only sources that may be duplicated in both systems should be those for which time-resolved data can be obtained. Since there are expected to be not more than one or two hundred such sources, it will not be efficient to provide a program for computer translation of NEDS to RAPS data. It will be cheaper to manually copy these source data, especially since much of the data for each source will be new. If, eventually, the use of the RAPS inventory is extended to cover much more data from other areas, then the possibility of computer transfer of data between the two systems should be re-examined.

Figure 3 shows a schematic of the inventory system.

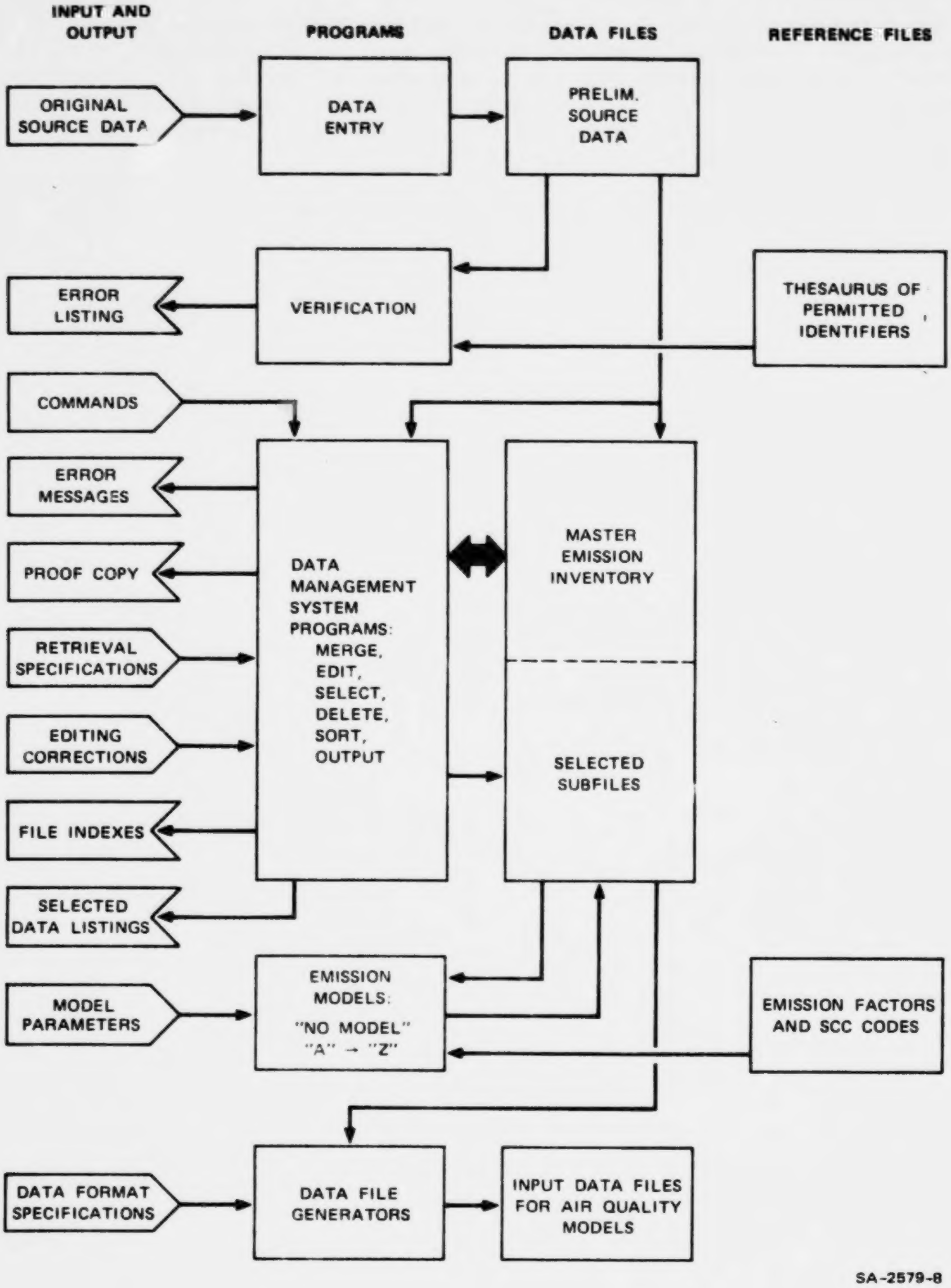

INPUT AND OUTPUT
PROGRAMS
DATA FILES
REFERENCE FILES
ORIGINAL SOURCE DATA
DATA ENTRY
PRELIM. SOURCE DATA
ERROR LISTING
VERIFICATION
THESAURUS OF PERMITTED IDENTIFIERS
COMMANDS
ERROR MESSAGES
PROOF COPY
RETRIEVAL SPECIFICATIONS
EDITING CORRECTIONS
FILE INDEXES
SELECTED DATA LISTINGS
DATA MANAGEMENT SYSTEM PROGRAMS: MERGE, EDIT, SELECT, DELETE, SORT, OUTPUT
MASTER EMISSION INVENTORY
SELECTED SUBFILES
MODEL PARAMETERS
EMISSION MODELS: "NO MODEL" "A" → "Z"
EMISSION FACTORS AND SCC CODES
DATA FORMAT SPECIFICATIONS
DATA FILE GENERATORS
INPUT DATA FILES FOR AIR QUALITY MODELS
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FIGURE 3 SCHEMATIC OF INVENTORY SYSTEM

D. Data Structures and Formats

1. Source Categories

The three principal categories of emission sources are point, line, and area. Because they require sufficiently different identification parameters, they should be filed by using different item data structures. They can be stored in separate computer files or in the same file in different item categories.

Point sources can be identified by the use of a group of identification parameters selected from those given in the manual for the NEDS inventory. Although this is a RAPS emission inventory, some of the NEDS identifiers are included primarily to facilitate data interchange between the two systems. The primary identifiers should be:

* Assigned source item number (sequence number assigned by inventory system);
* Source category (e.g., power station, foundry, refinery);
* Source name (name of company, organization, or generic name if it has no specific name);
* Plant No., Point No.;
* Street address (or nearest street identification);
* City, County, State, AQCR No.

The UTM coordinates are not included in the source identifiers of point sources, because each stack of a multistack source will have its UTM coordinate position in the data item. If some stacks at a plant have different emission values or time sequences than others, more than one data item will be needed to inventory that plant. The Point No. is intended to identify such different sources within a plant.

The NEDS Source Category Code (SCC) is included as part of the identification of each consumed or manufactured product, rather than as a single-valued source identifier, because a source may utilize more than one product. The code includes both the material and process identification.

Location, source category, and sequence number identify area sources. Predetermined area sizes or shapes need not be allocated. Any closed simple area bounded by straight lines can be uniquely specified by the coordinates of the intersections of these lines taken in order. Thus the areas can be selected on the basis of convenience and appropriate internal contents without size or shape restrictions. Area sources can overlap; for example, an area identified for automotive emissions may include or overlap an apartment house area. The recommended identifiers for area sources are:

* Item number;
* Source category (e.g., automobiles, residential, dump);
* Area number (assigned sequence number);
* List of UTM coordinates of corners of boundary (starting with most westerly or southwest corner and going clockwise);
* City, County, State, AQCR No.;

- English language paragraph for general descriptive purposes. This should always include a street or locality description to supplement the UTM coordinate specification.

Identification of line sources will be similar to that for area sources except for the significance of the UTM coordinate list. The sequence of the UTM coordinates of the end points of a connected sequence of straight lines approximating the position of the source will locate each line source.

2. Data Item Formats

The items of the file will consist of point sources, area sources, or line sources.

Many sources will have fuel-burning data or process rate data instead of direct emission data. For some plants, the materials being produced may be significant sources of air pollutants, and these products can be included in the process category. Or, if data are lacking on either, an activity may have to be identified to which an average emission model can be applied (for example, automobile traffic). An activity might be included for some point sources (like a freight terminal), if the fuel or emission rates cannot be measured directly. Thus, three different components of the source data that can be used in combination for some sources are:

- Emission data
- Consumption and process data
- Activities.

In the case of consumables, the data element would describe rates of consumption. For activities, the possibilities are so varied that no single standard format for descriptive data is likely to be usable. One example of an activity, automobile traffic, is discussed in the line source category.

Except where direct emission data are available for a source, the emission can be calculated from the consumption or activity data by application of emission factors and emission models, and the result entered into that source item in the inventory file as calculated emission data.

a. Point Sources

Any point source may emit one or more of several pollutants of interest. If data capacity is provided in each item for all possible pollutants, the file structure will be inefficiently used (mostly empty). A more appropriate structure would use list elements implemented such that each pollutant or consumable actually included in the item list is associated with a pointer to an associated data element, each of which is a logical record of variable length. This will permit efficient use of computer storage and efficient retrieval and selection of data for construction of model input files.

In some data reference systems, the system automatically maintains the pointers on the basis of the data linkages specified during data entry. If the system does not provide internal pointers to associated data elements, then explicit addresses (such as record number) must be written in the file, and the user must maintain the necessary address directory.

Figure 4 illustrates a sample point source item.

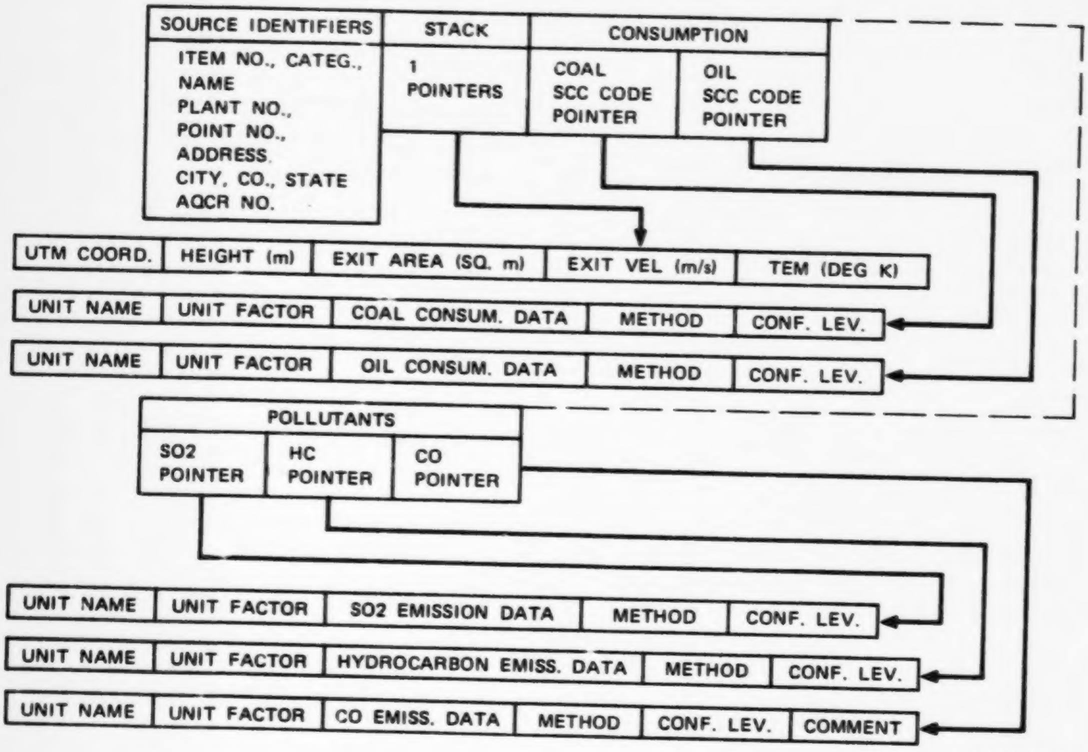
SOURCE IDENTIFIERS
ITEM NO., CATEG., NAME
PLANT NO., POINT NO., ADDRESS
CITY, CO., STATE
AQCR NO.
STACK
1 POINTERS
CONSUMPTION
COAL SCC CODE POINTER
OIL SCC CODE POINTER
UTM COORD.
HEIGHT (m)
EXIT AREA (SQ. m)
EXIT VEL (m/s)
TEM (DEG K)
UNIT NAME
UNIT FACTOR
COAL CONSUM. DATA
METHOD
CONF. LEV.
UNIT NAME
UNIT FACTOR
OIL CONSUM. DATA
METHOD
CONF. LEV.
POLLUTANTS
SO2 POINTER
HC POINTER
CO POINTER
UNIT NAME
UNIT FACTOR
SO2 EMISSION DATA
METHOD
CONF. LEV.
UNIT NAME
UNIT FACTOR
HYDROCARBON EMISS. DATA
METHOD
CONF. LEV.
UNIT NAME
UNIT FACTOR
CO EMISS. DATA
METHOD
CONF. LEV.
COMMENT

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FIGURE 4 SAMPLE POINT SOURCE ITEM

The Stack component can describe any number of stacks at one point source. The element will contain the number of stacks, and a pointer to a data element for each stack containing a standard sequence of parameters: UTM coordinates, height(meters); exit area(square meters); exit velocity(meters/second); gas temperature(deg K).

If each of the second level data elements, as shown in the example, consists of a fixed sequence of data components, with only the last one (comments) optional, then the separate components do not require system identifiers.

b. Area Sources

Because the format of an area or a line source will have to provide for an indefinite number of UTM coordinates, these are placed in a separate data element. The area and line sources are defined in terms of a single principal pollutant; thus only that pollutant is identified, instead of a list of them as in a point source item. The emission of that pollutant will usually have to be computed from consumption data by means of standard emission factors, so the consumption data should also be included in each area source description in the inventory.

Figure 5 shows a sample area source item.

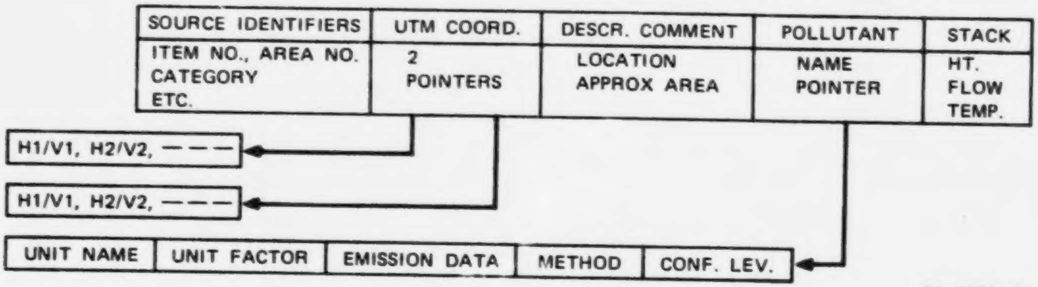
SOURCE IDENTIFIERS
ITEM NO., AREA NO.
CATEGORY
ETC.
UTM COORD.
2
POINTERS
DESCR. COMMENT
LOCATION
APPROX AREA
POLLUTANT
NAME
POINTER
STACK
HT.
FLOW
TEMP.
H1/V1, H2/V2, — — —
H1/V1, H2/V2, — — —
UNIT NAME
UNIT FACTOR
EMISSION DATA
METHOD
CONF. LEV.

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FIGURE 5 SAMPLE AREA SOURCE ITEM

This example shows how two separate areas can be included in one area source item. An area source item can describe a set of non-contiguous areas to avoid duplication of the complete description of each of a set of area sources having identical emission characteristics. The number in the UTM Coordinate component specifies the number of different areas described in the item. For each area, there will be a separate data element containing its coordinates.

The Stack data in an area source item refers to an equivalent stack for purposes of dispersion modeling. The stack area is assumed to be the whole source area; volumetric flow rate is estimated from fuel or other consumption data. The consumption data component is not shown in this sample; it is structured the same as the consumption component shown in the point source sample.

Only a very slight change in format is needed to use a single area source item to describe the emission of more than one pollutant, as in point sources. Therefore, although we are here suggesting a single pollutant per area source item, that choice can be made by the emission inventory manager at the time that the areas are defined.

c. Line Sources

An important type of line source is automobile traffic. The format of line source items will differ from area sources primarily in the significance of the UTM coordinate list that will be the endpoints of straight-line segments approximating the road route. The category name "Road" can identify this type of source. The activity name can be "Automobile", and additional elements should be appended to the item under the names:

* Traffic (average vehicle flow, average speed, vehicle mix)
* Way (type, dimensions).

3. Other Data

File data describing the composition of fuels or other consumed materials may be useful in the inventory, if they are variable for different sources. A data element for composition can be attached to any entry in the consumption list by a second pointer. The pointer identification is: Pointer 1 to the consumption data element, Pointer 2 to the composition data element (if any).

The composition element can be a paired list of impurity element symbol or compound formula and weight fraction for as many constituents as are signifacant. The element or formula name can be terminated by a blank, and each pair can be separated by a slash. A sample is shown below.

```
S .02 / As .005
```

Another category of data that may be needed in some source items is certain special emission factors, such as those for nitrogen oxides, for sources where there are actual measurements of the factors. The measured emission factors can be added to the data structure by a third pointer under the appropriate consumable. The emission factor data element will have to identify each pollutant calculated by each factor. The data can be entered in the same format as that for composition, above, except that the identifiers will be pollutants and the numerical values will be emission factors.

Other source data may be added to any item by use of a labeled pointer to an extension record. Any number of such extension records may be attached to any item, but no additional storage space need be allocated to items that do not include such data.

4. Data Element Formats

Most of the data elements will be numeric or text constants and will require very little formal formatting. Real numbers must be written in standard notations such as decimal or exponential (ie. 94.27, 1.03 E-4). Text elements can be written free-form. It is often convenient to have one printing character such as "#" or "$" defined as a text element terminator. A continuation character can also be defined to enable the entry of multiline text elements. On some systems, the linefeed key is most effective for this purpose, because it initiates a new line at the terminal.

The emission and consumption data elements, on the other hand, can have a large variation in amount of data and should allow for different levels of time resolution. These therefore require format rules to provide exact identification of descriptors and data.

Since the data elements for consumption data may deal with a large variety of consumable products, a single unit of measure (e.g., grams/second) may not always be appropriate. Therefore, the first component of the data element is the name of the unit of measure and the second is the conversion factor to convert that unit to the standard inventory system unit.

For those sources for which a series of time-sequence measurements are available, it will be useful to describe the emission or consumption by those measurements. On the other hand, there will be many sources, especially area sources, for which only approximate estimates can be made, usually on the basis of some repetitive patterns over time. The format rules described below can be used to describe either a consecutive time sequence or repetitive time patterns or any convenient combinations of both. This component of the data element may be very long (up to 75,000 characters), but it will still be one logical record.

Each emission or consumption data element also includes a component for Method, for Confidence Level, and an optional component for any further comments that may be considered useful to add for documentation of the data. Method will generally be described by means of a concise standard descriptor or abbreviation of the name of the method used to obtain the data. For example, "EF" can identify emission values calculated from consumption data by application of the standard Emission Factor table. Confidence level should be an estimate of the probable error of the values given, based on a knowledge of the errors of the method of measurement, or the reliability of the source data.

The emission element format is the following:

```
Data Element = Unit name + Unit factor + Data Part + Method +
                 Conf. Level + Comment(optional)
Data Part = Time Part/Data Part  or  Value
Time Part = Time Code:Time Range  or  (Time Part, Time Part, ...)
Time Range = Time Identifier  or  Time Identifier-Time Identifier
Time Code = A, M, W, D, or H
```

This definition is hierarchically recursive, so that nested data sets can be constructed by combination. For example,

M:11-2/H: means Monthly groups, Nov. to Feb. range, hourly data. Because there are no time units specified between months and hours, it also means that the hourly pattern repeats daily during that range of months.

Operator characters are:

: means a 'range/data' sequence follows;
/ means a datum or a data set follows;
, is a separator between components of a simple data set;
; is a separator between data sets of a multiple data set;
- is a connector between first and last time identifiers (inclusive) of a time range;
( ) enclose a multiple group of time pattern descriptions.

Some examples are:

M: 1/1.4,2/1.7,3/1.9,----12/1.3; is a set of values for each of the 12 months.
H: 1/9.7,2/10.3,----24/8.2; is a set of 24 hourly values, for some "average" day.
(M:11-3/D:7-1/H:21-7, M:6-7/D:1/H:22-6)/1.4; specifies a repeating pattern of 8 pm to 7 am on Saturdays and Sundays during November through March, and 9 pm to 6 am on Sundays during June and July, with an emission value of 1.4 units during each of these intervals.

This looks complicated, but the notation is self-descriptive once the user becomes familiar with the meaning of the punctuation symbols. It satisfies two important criteria; it can concisely describe a large variety of possible time-dependent data, and it can be read by machine.

There appears to be no way to design a preprinted, "fill in the blanks", form for data to be entered in this format. The reason is that the format is designed to provide a concise method of describing any sequence or repetitive pattern of time-dependence using several different time units, so that the syntax must be dynamic as in a language, rather than a static syntax that can be preconstructed.

For each time interval code, the total period covered, and the notation is shown in Table 9.

Table 9
Time Interval Codes and Ranges

Time Interval	Code	Period	
Annual	A:	range in calendar years to which the data applies (e.g., 69-73)	
Monthly	M:	1 year	1-12 values
Weekly	W:	1 year	1-53 values
Daily	D:	1 week	1-7 values; 1=SUN, 2=MON, 3=TUE, 4=WED, 5=THU, 6=FRI, 7=SAT
Hourly	H:	1 day	1-24 values

All the time units refer to inclusive intervals (i.e., M:1-2 means January and February). Counted hours, not clock time, is used (i.e., H:7-8 means from 6 am to 8 am). Zero (0) is avoided because it leads to confusion in data entry and because it is not common usage. Since the week is defined to be Sunday through Saturday, a year will generally begin and end with a partial week, so that there will always be 53 identifiable weeks in every year.

The emission data should correspond to the average emission during the specified interval, for a current example of the period. Multi-nested intervals can be used where sufficient data exist and the emission changes considerably over the larger time intervals. For example, hourly emission data for an average day during each of several months may be useful, if the emission rates change considerably through the year.

The large choice of time intervals permits the entry of detailed time-dependence of emission if the information is available and less detailed averages when that is all that is known. If data are available only for portions of a data set, only those elements of the set need be identified and entered in the inventory because the format includes a numeric identifier for every time interval for which data are entered.

Since M: and W: interval sets both cover a period of one year, they are mutually exclusive. The D: and H: intervals can be used with any one of the first two in a multiple set, and D: and H: can also be combined. By the use of these formats, each emission data element can contain as few as one value, averaged over a typical year, or a value for every hour of a year.

Although it uses a concise notation, this format is sufficiently redundant to permit recognition of many entry errors. Manual proofreading will detect many common typing errors, and the use of the computer for checking the internal consistency of data and the syntactic correctness of the data elements will also be feasible.

5. Summary Listing

The following listing summarizes the form and arrangement of identifiers in a source item. Generally, most of the entries will be data relative to higher level identifiers and an identifier for lower level data. They will only be entered into an item if they represent actual information so that only a small fraction of the entries in this table would occur in any single inventory source item. Many of the entries in the table (e.g., names of pollutants) represent only a few examples of an unlimited set of possibilities and are included to display their arrangement and notational style.

- Point
  - Identifiers
    - NO. — Item number. For file maintenance.
    - Category — Type of source
    - Name — Ordinary name of facility
    - Street address
    - City, County, State, AQCR No.
  - Pollutants
    - SO2 — Chemical formula or abbreviated name
      - Unit   Emission rate data   Method   C.L.   Comment
    - HC
      - Unit   Emission rate data   Method   C.L.
    - .
    - .
    - .
  - Consumption
    - Coal   SCC code
      - Unit   Consumption rate data   Method   C.L.
    - .
    - .
    - .
  - Activities
    - Trucks
      - Count/day
    - Helicopters
      - Count/day   Comment
  - Stacks   Count
    - UTM coord.   Height   Exit area   Exit velocity   Temp.
    - .
    - .
    - .
- Area
  - Identifiers
    - NO.
    - Category
    - Area Number — Assigned for map reference
    - City, County, State, AQCR No.
    - UTM Coord   Area count
      - Coord list
    - Description of area
  - Pollutant   Heat
    - Unit   Emission rate data   Method   C.L.
  - Consumption   Fuel Gas   SCC code
    - Unit   Consumption rate data   Method   C.L.
  - Activity
    - Autos
      - Flow   Speed   Veh. mix
    - Population
      - Persons   Housing units   Hous. mix
- Line
  - (See Area--elements are essentially identical)

E. Format Extensions for Batch Data Entry

To prepare the data items off-line for batch entry, it is necessary to provide additional format conventions to indicate the logical boundaries of data components and the hierarchic level structure of each data item. If an existing data management system is obtained, it will have its own formats for this purpose.

If a data management system is expected to be used to maintain the RAPS Emission Inventory, but the scheduling of data processing requires that data be prepared for machine entry before the entry formats for that system are available, then this format can be used to enter the data onto machine-readable media, and the formats converted later to those required by the system. The special-purpose conversion program will be a temporary program used only once to process the data previously entered. After that, all new data will be prepared directly in the system format.

This extended format can also be used for the purpose of making sequential files for temporary use without the use or support of a hierarchic data management system. For this latter purpose, it is also useful to include a code to show whether a given data item is a current one in the file or has been replaced by an updated version, because the actual deletion of items and compaction of the file will require processing by a file maintenance program.

The characters chosen as delimiters for this extended format have not been used for the internal data formatting. These data structures, together with all format defining characters, can be implemented within the conventional 64-character ASCII subset that is available on most keyboard data entry devices and printers:

[n	Left bracket, followed by an integer, indicates opening of a hierarchic data level. n = data level
n]	Close data level n, and all inner levels.
< >	Delimiters of data element names
#	Pound sign - data element separator.

Each new data item will begin with [1. To indicate the status of the item, the integer 1 can be changed. [1 means that the item is a current one in the file; [0 means that it has been superseded. A partial example of a data item shows the manner of use of these format controls:

```
[1 <P> [2 <SI> # 234# MFG# UNIVERSAL HORSE-COLLARS# 999 WHINNY ST.,
ST. LOUIS, MO.# 70# 2] [2 <POLLUTANTS> # SO2 [3# G/S # M:1/1.4,
2/1.7, 3/1.9 ----- 12/1.3# 3] # HC [3# KG/HR # A:69-72/19.5# 2] [2
<STACK> # 1 [3# 321.0,963.1# 22# 0.83# 35# 300# 1]
```

The <P> denotes this as a point source (not needed unless all types of sources are included on one file). The denotation <SI> is the abbreviated name for Source Identifiers, a level 2 data structure. The denotation <POLLUTANTS> is the name of the next level 2 structure, but it contains two level 3 data sets. The terms SO2 and HC are not names of data structures, they are data, but a level 3 data structure depends from each of them. <STACK> is the name of another level 2 data component, containing the parameters of each stack.

F. Implementation

The next steps in the implementation of this emission inventory are the following:

- Specify the set of point sources, area sources, and line sources in the St. Louis metropolitan area that will be used as the initial basis for the RAPS emission inventory.

- Assemble the data applicable to these sources from other inventories and from other data sources.

- If a general-purpose data management system is not available, then write a system of programs for file definition, data entry, and updating of the emission inventory.

- Specify data entry procedures based jointly on the formats described in this report and the capabilities of the system. Any conflicts must be resolved by changing the format structures or the choice of punctuation characters, as necessary.

- Enter a small set of data to verify the correctness of the structure and the formats of the data base.

- Enter and proof-check the entire initial data set.

- Write and test the programs for
  - Computing emission values from consumption data;
  - Accessing data items on the basis of specified ranges of time, emission values, or source locations;
  - Constructing input data files for atmospheric models.

- Produce input data files for models using either data system procedures or separate computer programs.

G. Specifications for Computer Programs

1. Data Management System

These systems usually consist of a group of interconnected programs. This specification concerns only the external features related to the operation of the RAPS Emission Inventory.

- * Data bases of 20 million character size, containing up to 2000 items, each including 10 to 100 data elements, in up to 4 hierarchic levels.
- * Batch data entry from punch cards, magnetic tapes, or disk files.
- * Capability for defining hierarchic data structures, including list components.
- * Symbolic naming of data components.
- * Unrestricted lengths of lists and records.
- * Retrieval of items by content or partial content of any data component, including logical combinations of retrieval specifications.
- * Editing and updating individual items or groups of items.
- * Interface for external programs to access data items and data components in the files.
- * (Optional) Capability of calling special subroutines within the data system for operations requiring recognition of specialized formats within a data component.
- * (Optional) Construction of data files in specified formats for use by external programs.
- * (Optional) Sorting and indexing selected subfiles by content.

2. Input and Output Subroutines for Emission Model Programs

These are intended to be standardized subroutines, callable by any emission model program to provide access to the emission inventory file.

The input subroutine must:

- Access source item via file address;
- Read consumption data component from source item;
- Extract SCC code, unit, time ranges, and consumption values;
- Read emission factor for SCC code from Emission Factor File;
- Convert values to the units required by the model.

The output subroutine must:

- Generate calculated emission data element for the pollutant and for the time ranges defined by the model, in the format required by the inventory;
- Append the emission element to the same source item from which the consumption data were read.

3. Verification Program

This can operate in three different ways. It can be part of a data entry program; it can be a separate program to correct preliminary data files prior to merging into the Master Inventory; or it can operate within the data management system on data sets retrieved by the system. It should perform these tasks:

- * Verification of syntax of formatted data components for logically correct usage of operator and delimiter characters.
- * Comparison of material names with those in a thesaurus file to verify that every name is one of an allowed set.
- * Printing listings of erroneous items with bad elements marked.

4. Data File Generator Program

This capability may be included in a complete data management system. It should do the following operations as a minimum, although more extensive formatting capabilities may be useful.

- * Accept user or file input of specifications for the exact sequence of data values and data representations required by an external program.
- * Take its input from a subset of the emission inventory file selected by the data system and extract data from data components (the input subroutine for the emission model can be used for this purpose).
- * Convert coordinate locations to the grid identification code used by the model.
- * Interpolate emission values, if necessary, to the time intervals required by the model.
- * Write the output file on the disk, magnetic tape, or punch cards, as specified.

VI TASK D: SURVEY AND EVALUATION OF EXISTING EMISSION INVENTORY DATA

A. Introduction

Air pollution studies have been conducted in the Saint Louis area for many years, and several emission inventories have been developed. To avoid any unnecessary duplication of effort, it was important to review the existing emission inventories, to compare their content with the information needed for RAPS, and, if they appeared to contain useful information, to transfer this information to the RAPS inventory.

The City of Saint Louis has been involved in air pollution control since its first antismoke ordinance was passed in 1893. Smoke and fumes were, of course, the first targets of pollution control efforts; even so, 50 or 60 years passed before effective pollution control measures were applied to the largest pollution sources of the Saint Louis area, the power plants and the steel mills. In 1964, an "Interstate Air Pollution Study, Saint Louis-East Saint Louis Metropolitan Areas" was undertaken by the U.S. Public Health Service. Questionnaires were sent out to determine fuel use and combustible waste disposal practices in the area as well as manufacturing activities. A revised emission inventory, still based on 1963 data, was published in December 1966 as Phase II of the interstate study.

After the Metropolitan Saint Louis Interstate Air Quality Control Region had been established, the first comprehensive inventory was taken in 1968, to serve as a basis for the Implementation Planning Program (IPP). This inventory included the jurisdictions of Jefferson, Saint Charles, and Saint Louis Counties and Saint Louis City in Missouri; and Madison, Monroe, and Saint Clair Counties in Illinois. Franklin County was added in 1969. Four additional Illinois counties, Bond, Clinton, Randolph, and Washington, were added to the air quality control region in 1971. Only sulfur dioxide (SO_2) and particulates were included in the initial IPP inventory. The more recent inventories contain estimates of carbon monoxide (CO), hydrocarbons, and oxides of nitrogen (NO_x) as well. The following inventories are described in some detail in Section II:

- IPP Emission Inventory-1968
- IBM Emission Inventory-1970
- DAQED Emission Inventory-1971

- NATO Emission Inventory-1971
- NEDS Emission Inventory-1973

In addition, the following traffic and transportation inventories are discussed:

- Streets and highways
- Railways and vessels

The emission inventories in current use by the Missouri and Illinois regulatory agencies were recently (Summer 1973) acquired and transferred to the NEDS files under another contract; therefore, they are not considered separately.

Contact was also established with research groups, such as the Metromex consortium, active in the Saint Louis area. However, these groups do not have any emission inventory data. Nor were any data available from industrial sources, such as the Waste Control Council.

The data available from the various air pollution control organizations deal with pollution arising from industrial, commercial, residential and traffic activities. There appear to be no direct emission data on such transient sources as agricultural spraying or fugitive dust.

B. Existing Emission Inventories for the Metropolitan Saint Louis Interstate Air Quality Control Region*

1. IPP Inventory-1968

The Implementation Planning Program (IPP) emission inventory covering sulfur dioxide and particulate matter in the six counties and the City of Saint Louis originally making up the Air Quality Control Region was assembled by the EPA Region VII office in 1968. This inventory was used by Argonne National Laboratory as a basis for diffusion modeling in the development of the IPP for Illinois and Missouri.

The 1968 inventory lists yearly emissions of SO_2 and particulates from 116 major spot sources and 316 area sources, on the basis of questionnaires and letters of intent filled out by local agencies. Typical printout pages are shown in Figures A-1 and A-2 in Appendix A.

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*The pioneering interstate study by U.S. P.H.S. is mentioned above on page 107.

2. IBM Inventory-1970

In 1970 the International Business Machine Company (IBM) compiled an emission inventory for the Office of Air Programs. This inventory included only three Missouri counties (Jefferson, Saint Charles, and Saint Louis) and Saint Louis City; therefore, it is not directly comparable with other inventories in the area.

Though it covers a smaller area, the IBM inventory is considerably more detailed than the IPP inventory. It contains data on 105 point sources, giving their location; stack parameters; fuel consumption data; and calculated SO_2, particulate, CO, hydrocarbon, and NO_x emissions in tons per year (Figure A-3, Appendix A). From these data, emission inventories were calculated for each of the political jurisdictions.

In the IBM inventory, area sources were treated by counties. Each county was divided into source areas, varying in size from 4 to 700 square kilometers. For each area, emissions of particulates, SO_2, CO, hydrocarbons, and oxides of nitrogen were calculated for domestic, commercial, and industrial sources, as well as for incinerators and motor vehicles. A summary of the data is shown in Figure A-4, Appendix A.

3. DAQED Emission Inventory-1971

The former Division of Air Quality and Emission Data (DAQED) acquired an emission inventory for the Saint Louis area by using the rapid survey technique described by Ozolins and Smith.[13] This technique is based on information available in most urban areas; it does not entail extensive surveys or sampling procedures. The results are, however, considerably more accurate than those derived by gross approximations based on published production or consumption data.

The inventory included SO_2, particulate matter, CO, hydrocarbons, and oxides of nitrogen. The data are given in metric units. Summary information on population, area, some background information, and air quality data, is shown in Tables 15 and 16.

4. NATO Emission Inventory-1971

The North Atlantic Treaty Organization (NATO) emission inventory for the Metropolitan Saint Louis Interstate Air Quality Region was prepared in 1969 to serve as a comparison and model for the development of emission inventories in Frankfurt, Germany, and Ankara, Turkey. The so-called NATO Emission Inventory covered the following pollutants:

Table 15

SAMPLE OF DAQED Inventory
SO_x Emission Summary

REGION ST. LOUIS, MISSOURI-ILLINOIS
COUNTIES Jefferson, St. Charles, St. Louis (Mo.); Madison, St. Clair (Ill.)
POPULATION 1 678 251 AREA 9 239 sq. km.

EMISSIONS	RAPID SURVEY SO_x tonne/yr.	PARTICULATE
FUEL COMBUSTION		
Power Plant	334 000	16 000
Residential	45 000	20 000
Ind. & Comm.	113 000	16 000
PROCESS	107 000	11 000
REFUSE DISPOSAL	575	1 500
TRANSPORTATION	4 600	8 000
TOTAL	604 000	169 000
Emissions per capita	0.360	0.101
% of total emissions from the 5/3 largest sources.	75%	28%

a.	Meramec, P.P.	Monsanto
b.	Portage de Sioux, P.P.	West Lake
c.	St. Joseph Lead	Wood River, P.P.
d.	Venice, P.P.	
e.	Wood River, P.P.	
f.		
g.		
h.		
i.		
j.		

BACKGROUND INFORMATION: St. Louis is located at the confluence of the Mississippi and Missouri Rivers and near the geographical center of the U.S. The terrain is flat. Winters are brisk but seldom severe and summers are hot and humid. Inversion potential is low.

EMISSIONS: Most of the sulfur oxide emissions are discharged during combustion at power plants and industrial sources. More than 7.2 million tonnes of 3% sulfur coal is consumed annually. The largest industrial process sources are smelting, sulfuric acid manufacturing and refineries. Particulates are emitted primarily from the combustion of coal, with an average ash content of 9%. Other large sources of particulates are the grain industry, steel mills, cement and ammonium nitrate plants and rock processing.

APPRAISAL OF AIR QUALITY: Emission rates for both SO_x and particulates are quite high, and, as a consequence, the quality of the atmosphere has undergone considerable degradation. This supposition is supported by considerable ambient data on both pollutants. These adverse pollutant levels are to be expected in an area with such a concentration and variety of widely distributed industries plus numerous large power plants.

REGION ST. LOUIS, MISSOURI-ILLINOIS

Table 16

SAMPLE OF DAQED INVENTORY
CURRENT AND TREND DATA, AMBIENT CONCENTRATIONS

A. TREND DATA

Station*		SO_2 ug/m^3							SUSPENDED PARTICULATE ug/m^3						
		64	65	66	67	68	69	TREND	64	65	66	67	68	69	TREND
U E. St. Louis 1 NASN	Ann. Av.									189	187**	148	114	112	-
**City	24-hr. Max.									401	323	249	229	209	-
U St. Louis 1 NASN	Ann. Av.	87			87	91	73		138	143	135	111	186		0
	24-hr. Max.	292			294	193	266		278	260	255	184	480		-
U St. Louis 2 CAMP	Ann. Av.	160	130	100	80	80		-			163	121	132	124	-
(SO_2 continuous)	24-hr. Max.	680	500	470	550	420		0			394	296	378	356	-
U St. Louis 1 City	Ann. Av.									319	154	179			
	24-hr. Max									514	649	524			
		AVERAGES ARE ARITHMETIC							AVERAGES ARE GEOMETRIC						

B. CURRENT DATA

Station*	Ann. Av.	SO_2 ug/m^3 24-hr. Max.	1968 1-hr. Max	SUSPENDED PARTICULATE ug/m^3 Ann. Av.	24-hr. Max.	1969
U E. St. Louis 1 NASN				112	209	
U St. Louis 1 NASN	73	266 (1969)				
U St. Louis 2 CAMP	80	420	1780	121	356	
U St. Louis 2 City				151	438	
U St. Louis 3 City				89	207	

---

*Station Location Codes: U= urban; S= suburban; R= rural.
Trend Column Codes: += upward trend; 0= no trend; -= downward trend.

REGION ST. LOUIS, MISSOURI-ILLINOIS

- Sulfur dioxide
- Particulates
- Carbon monoxide
- Hydrocarbons
- Oxides of nitrogen

Essentially, this inventory was an updating from the IPP and DAQED emission inventories of all area and major point source emissions. In June, 1971, the NATO inventory was further updated by using new emission factors.

The NATO inventory is the most versatile of the inventories discussed so far. The data are grouped in the following 23 sections:

(1) Summary if Air Pollutant Emissions, Study Area.

(2) Summary of Air Pollutant Emissions, Saint Louis City, Missouri.

(3) Summary of Air Pollutant Emissions, Saint Louis County, Missouri.

(4) Summary of Air Pollutant Emissions, Jefferson County, Missouri.

(5) Summary of Air Pollutant Emissions, Saint Charles County, Missouri.

(6) Summary of Air Pollutant Emissions, Franklin County, Missouri.

(7) Summary of Air Pollutant Emissions, Madison County, Illinois.

(8) Summary of Air Pollutant Emissions, Monroe County, Illinois.

(9) Summary of Air Pollutant Emissions, Saint Clair County, Illinois.

(10) Summary of Air Pollutants from Point Sources.

(11) Summary of Air Pollutants from Area Sources.

(12) Combustion of Fuels, Stationary Sources.

(13) Transportation Sources.

(14) Process Losses.

(15) Emissions from Evaporative Losses.

(16) Emissions from Solid Waste Disposal.

(17) Point Source Emissions.

(18) Area Source Emissions (272 grids).

(19) Annual Fuel Consumption (by counties).

(20) Housing Units (by jurisdictions).

(21) Population, Housing Units (by grids).

(22) Emission Densities (tons km^{-2}).

(23) Flights per year (various airports).

Samples from the inventory are shown in Figures A-5 through A-10, Appendix A.

5. NEDS Inventory-1973

The inventories discussed so far show the gradual evolvement of the techniques for collecting and processing inventory data. The earliest inventory, the IPP inventory, contained information on only two pollutants, sulfur dioxide and particulates, while subsequent inventories include also data on carbon monoxide, hydrocarbons, and oxides of nitrogen. The data collection methods have also become more reliable. For the IPP inventory, information on area source emissions was obtained from gross estimates on fuel delivery and consumption for the entire area under study. The use of the rapid survey technique for the DAQED inventory, which breaks down the information into geographic areas of the community and makes use of formulas using degree-days (a unit representing the deviation from the mean ambient temperature--65°F--for one day), the number and size of dwellings, and other refinements, provided considerably more accurate estimates of emissions from area sources. Similar techniques were used for all subsequent inventories.

A comparison of the presentations of data shows an increasing degree of sophistication and usefulness indicated by the various ways in which the data are broken down and presented, for example, in the NATO inventory.

The actual emissions of pollutants shown in the tabulations have been continuously updated to reflect current practices as new sources came into being or to reflect the installation and effect of control equipment. For this reason, the inventories currently maintained by the local and state regulatory agencies, such as the Saint Louis City or County Air Pollution Control Office, are the only ones which can be used for the purposes of RAPS. The data in these inventories, some of which are in the form of computer printouts (others are on Inspectors' Report Sheets), have recently (Summer 1973) been acquired and entered into the National Emission Data Systems (NEDS) inventory. The characteristics of this inventory system, presented in APTD-1135, "A Guide for Compiling a Comprehensive Emission Inventory,"[14] are discussed below.

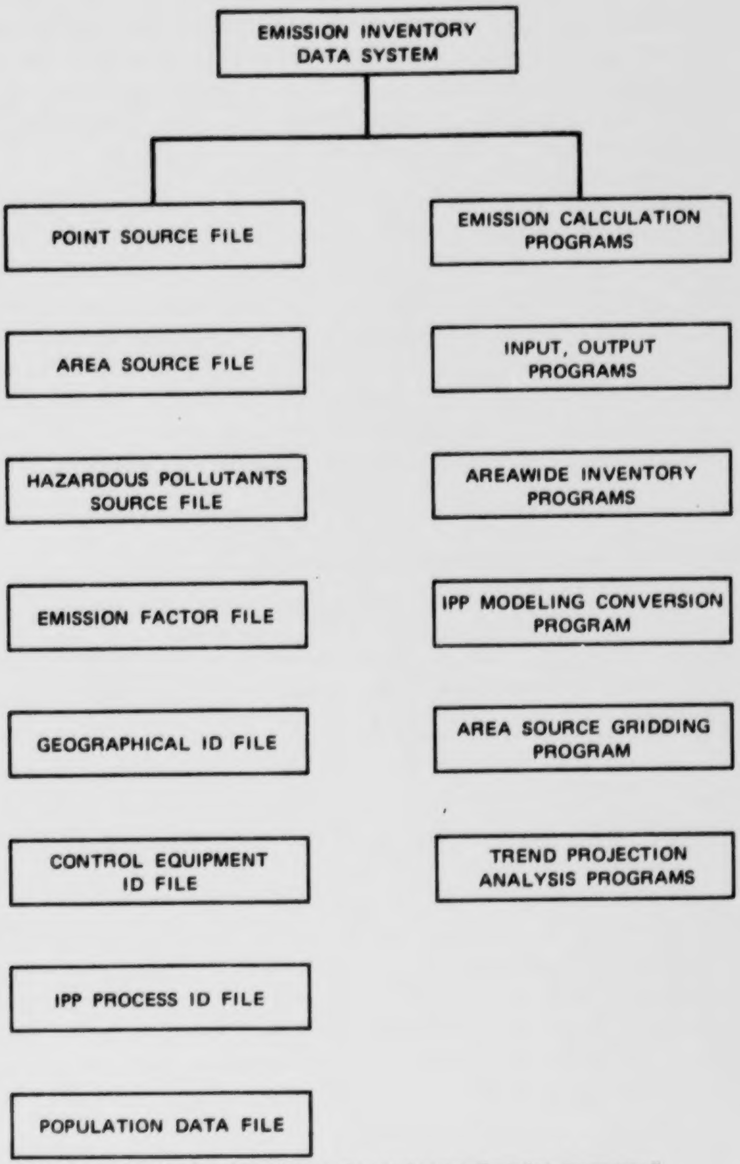
The NEDS was created by the EPA Office of Air Programs to provide a uniform format for source inventory data on a national scale. It consists of a number of separate files suitable for computerized processing and has provisions for storing data for both point and area systems as well as separate files containing various input/output, maintenance, and editing programs. The concept is shown in Figure 6.

The system distinguishes between point sources (emitting at least 100 tons per year) and area sources for the primary pollutants: particulates, SO_2, CO, hydrocarbons, and NO_x. The decision to designate sources emitting more than 100 tons per year of primary pollutants as point sources is based on the estimate that a 100-tons-per-year source would produce, under average meteorological conditions, an ambient concentration of about 5 to 8 micrograms of pollutant per cubic meter. This is about 10 percent of the secondary annual federal air quality standard for SO_2 or particulates. (Page 10-2 of APTD-1135.[14])

In addition, about 70 compounds or categories of industrial sources are designated as point sources regardless of quantities of emissions.

A point source is defined, therefore, as any emitting point or plant or facility whose summation of emitting points totals 100 tons or more per year of any one of the five primary pollutants: CO, SO_2, NO_x, particulates, or hydrocarbons; or as any of the pollutant sources listed below, regardless of quantity of emissions.

- Chemical process industries: adipic acid, ammonia, ammonium nitrate, carbon black, charcoal, chlorine, detergent and soap, explosives (TNT and nitrocellulose), hydrofluoric acid, nitric acid, paint and varnish manufacturing, phosphoric acid, phthalic anhydride, plastics manufacturing, printing ink manufacturing, sodium carbonate, sulfuric acid, synthetic fibers, synthetic rubber, terephthalic acid.
- Food and agricultural industries: alfalfa dehydrating, ammonium nitrate, coffee roasting, cotton ginning, feed and grain, fermentation processes, fertilizers, fish meal processing, meat smoke houses, starch manufacturing, sugar cane processing.


EMISSION INVENTORY DATA SYSTEM
POINT SOURCE FILE
AREA SOURCE FILE
HAZARDOUS POLLUTANTS SOURCE FILE
EMISSION FACTOR FILE
GEOGRAPHICAL ID FILE
CONTROL EQUIPMENT ID FILE
IPP PROCESS ID FILE
POPULATION DATA FILE
EMISSION CALCULATION PROGRAMS
INPUT, OUTPUT PROGRAMS
AREAWIDE INVENTORY PROGRAMS
IPP MODELING CONVERSION PROGRAM
AREA SOURCE GRIDDING PROGRAM
TREND PROJECTION ANALYSIS PROGRAMS

SOURCE: "Guide for Compiling a Comprehensive Emission Inventory," Environmental Protection Agency (1972).

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FIGURE 6 EMISSION INVENTORY SYSTEM CONCEPT

- Metallurgical industries: aluminum ore reduction, copper smelters, ferroalloy production, iron and steel mills, lead smelters, metallurgical coke manufacturing, zinc (primary metals industries); aluminum operations, brass and bronze smelting, ferroalloys, gray iron foundries, lead smelting, magnesium smelting, steel foundries, zinc processes (secondary metal industries).
- Mineral products industries: asphalt roofing, asphaltic concrete batching, bricks and related clay refractories, calcium carbide, castable refractories, cement, ceramic and clay processes, clay and fly ash sintering, coal cleaning, concrete batching, fiberglass manufacturing, frit manufacturing, glass manufacturing, gypsum manufacturing, lime manufacturing, mineral wool manufacturing, paperboard manufacturing, perlite manufacturing, phosphate rock preparation, rock, gravel, and sand quarrying and processing.
- All petroleum refining and petrochemical operations.
- All wood processing operations.
- Petroleum storage (storage tanks and bulk terminals).
- Miscellaneous: fossil fuel steam electric power plants, municipal or equivalent incinerators, open burning dumps.
- Hazardous pollutant sources.

Another category of point sources, regardless of quantities of emissions, are pollutants designated as hazardous. A list of these is still in preparation.

The location of all point sources is described using Universal Transverse Mercator (UTM) coordinates. This system, designed by the U.S. Army[15] provides projections of square grid zones with convenient measuring units. The system has the advantage of continuity and uniformity for the country, and it is rapidly becoming the accepted system of base coordinates for a body of technical information.

The NED System contains other files beside the source inventory. These are

- The Population Data File, which contains such information as number of household units in an area, number of manufacturing employees, number of retail and wholesale establishments. This information is used to calculate emissions where no direct data are available, as for example, emissions resulting from solid wastes, fuel consumption for space heating, and others.

- The Emission Factor File, which contains conversion factors that provide an estimate of the production of a given pollutant by a process or activity. For example, it has been estimated that two pounds of solvent per person per year are emitted from dry cleaning plants in moderate climates. In conjunction with appropriate population data contained in the Population Data File, the total amount of hydrocarbons per unit area can thus be calculated. The most complete collection of factors has been published by EPA in the Compilation of Air Pollutant Emission Factors (AP-42).
- The Control Equipment File, which contains information on types and efficiencies of various control devices.

As indicated in Figure 6, the NED System contains a number of programs; these include not only "housekeeping" programs, such as those for input and output, editing, and emission calculation, programs permitting outputs by area, source classification, and pollutant, as well as conversion programs selecting data for implementation planning programs and trend analysis.

The system is designed to provide data on annual emissions of pollutants; estimates of shorter emission rates--weekly, daily, or hourly--can be calculated automatically by applying appropriately resolved production throughput, or other control data to the base emission figure. Such an approach can provide the time resolution necessary for RAPS where no actual hourly measurements are available. Typical printouts are shown in Figures A-11 and A-12 in Appendix A.

Table 17 shows a comparison of the various emission inventories. Only limited conclusions can be drawn from a comparison of these data. The data in the IBM inventory, covering a much more limited area, are not comparable at all; nor do the other inventories cover exactly the same territory. The data shown for the NEDS inventory have been adjusted to include only the counties included in the two NATO inventories; thus, these three inventories are directly comparable. Good agreement is shown for sulfur oxides (if a correction of about 100,000 tons per year, corresponding to the SO_2 emissions of Franklin County, is added to the IPP and DAQED figures). The figures for the total emission of particulates and carbon monoxide are much higher in the NEDS inventory than in the older inventories; the emission values for hydrocarbons and nitrogen oxides again show quite good agreement (the contribution from Franklin County is fairly small).

Table 17

COMPARISON OF EMISSION INVENTORIES FOR THE METROPOLITAN SAINT LOUIS INTERSTATE AIR QUALITY REGION*

Inventory Name	Data Base Year	Area*	Emission Inventory Technique	Emission Totals (tons/year)				
				Sulfur Oxides	Partic-ulates	Carbon Monoxide	Hydro-carbons	Nitrogen Oxides
IPP	1968	Franklin County not included	IPP forms filled out by local agencies from questionnaires (Mo.) or letters of intent (Ill.)	612,318	192,800	- -		
IBM	1970	Madison County, Franklin County, Saint Clair County and Monroe County not included	IPP point source data (1968) updated)		Not	comparable		
DAQED	1967 to 1968	Franklin County and Monroe County not included	Rapid survey	662,490	186,290	1,644,640	326,280	180,780
NATO -1	1969	----	Updated IPP data	746,160	185,910	1,417,460	187,650	218,610
NATO -2	1969	----	Updated IPP data New emission factors	744,930	184,970	1,865,720	288,130	295,340
NEDS	1972†	----	Updated IPP data	757,105	347,379	3,803,460	282,982	298,491

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*Includes the following jurisdictions, except as noted: Jefferson County, Saint Charles County, Saint Louis County, St. Louis City, Franklin County, Madison County, Monroe County, Saint Clair County.

†The data were put into NEDS in 1973, but were based on earlier years. NEDS is updated every 6 months.

The inventories are too close in time to allow any clear trends to show up. The differences are probably better viewed as examples of changes produced by better inventory techniques. Even so, closer examination of NEDS data shows examples of values that suggest the desirability of rechecking the data; for example, a CO emission of 1,340,000 tons from a single blast furnace or evaporation of 14,000 tons from a single tank suggests a check. The former amounts to almost 35 percent of the total estimated emission of carbon monoxide for the air quality control region; if correct, it will certainly affect the view of carbon monoxide as a pollutant whose origin is primarily related to traffic sources.*

As the NEDS inventory represents the current understanding of emissions in the Saint Louis area, it could and should be used for planning purposes. For example, it can serve as a basis for the determination of the number of point sources that should be monitored for the RAPS emission inventory, since only the most important point sources can be monitored. A review of the point sources listed in the NEDS inventory shows the breakdown of point sources by size in Table 18 and Figure 7.

Table 18

NUMBER OF POINT SOURCES

Pollutant	Emission Category (tons/year)			
	> 10*	$> 10^2$†	$> 10^3$†	$> 10^4$†
Particulates	271	99	28	6
SO_x	345	184	67	13
NO_x	352	111	24	7
HC	269	99	23	1
CO	93	31	11	6

*Data from NEDS printout of 19 December 1973. Includes some sources not in earlier printouts.

†Data from NEDS printout of 28 August 1973.

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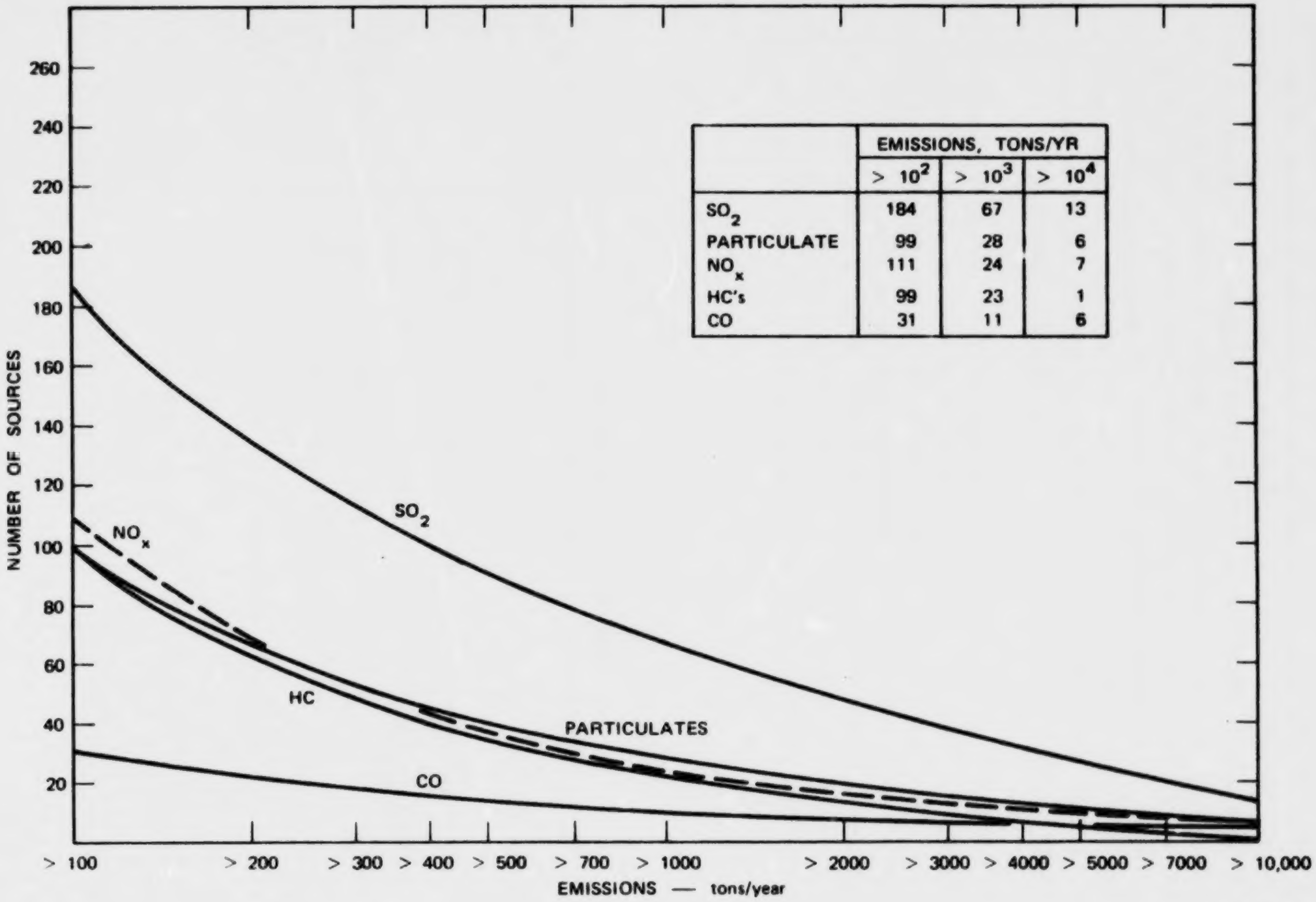
*Both of these figures are erroneous (Personal Communication, Illinois Environmental Protection Agency, December 1973).



	EMISSIONS, TONS/YR		
	> 10^2	> 10^3	> 10^4
SO$_2$	184	67	13
PARTICULATE	99	28	6
NO$_x$	111	24	7
HC's	99	23	1
CO	31	11	6

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FIGURE 7 NUMBER OF POINT SOURCES AND EMISSIONS

This information is even more relevant if it is arranged to indicate what percentage of total emissions can be evaluated by monitoring a given number of sources. By referring to Figures 8 through 12, we see that we can monitor, say, 90 percent of all emissions from point sources greater than 1 ton/year by observing about 40 sources for SO_2, about 5 for CO, 50 for particulates, and 100 for hydrocarbons; oxides of nitrogen, however, would require the monitoring of 330 sources to achieve the 90 percent level. Alternatively, we could decide to use an emission of 100 tons per year as a cutoff point. In that case, 184 sources for SO_2, 31 sources for CO, 99 sources for particulates and hydrocarbons, and 111 sources for NO_x should be monitored. Table 19 summarizes.

As mentioned above (page 114) the 100 ton-per-year break point is consistent with a 10 percent sensitivity for modeling or measuring concentrations near the levels of the national secondary air quality standards. While this is probably equally suitable for the modeling verification studies of RAPS, the sensitivity of such multisource models to this break point should be investigated by specific studies as recommended above on pages 48-49.

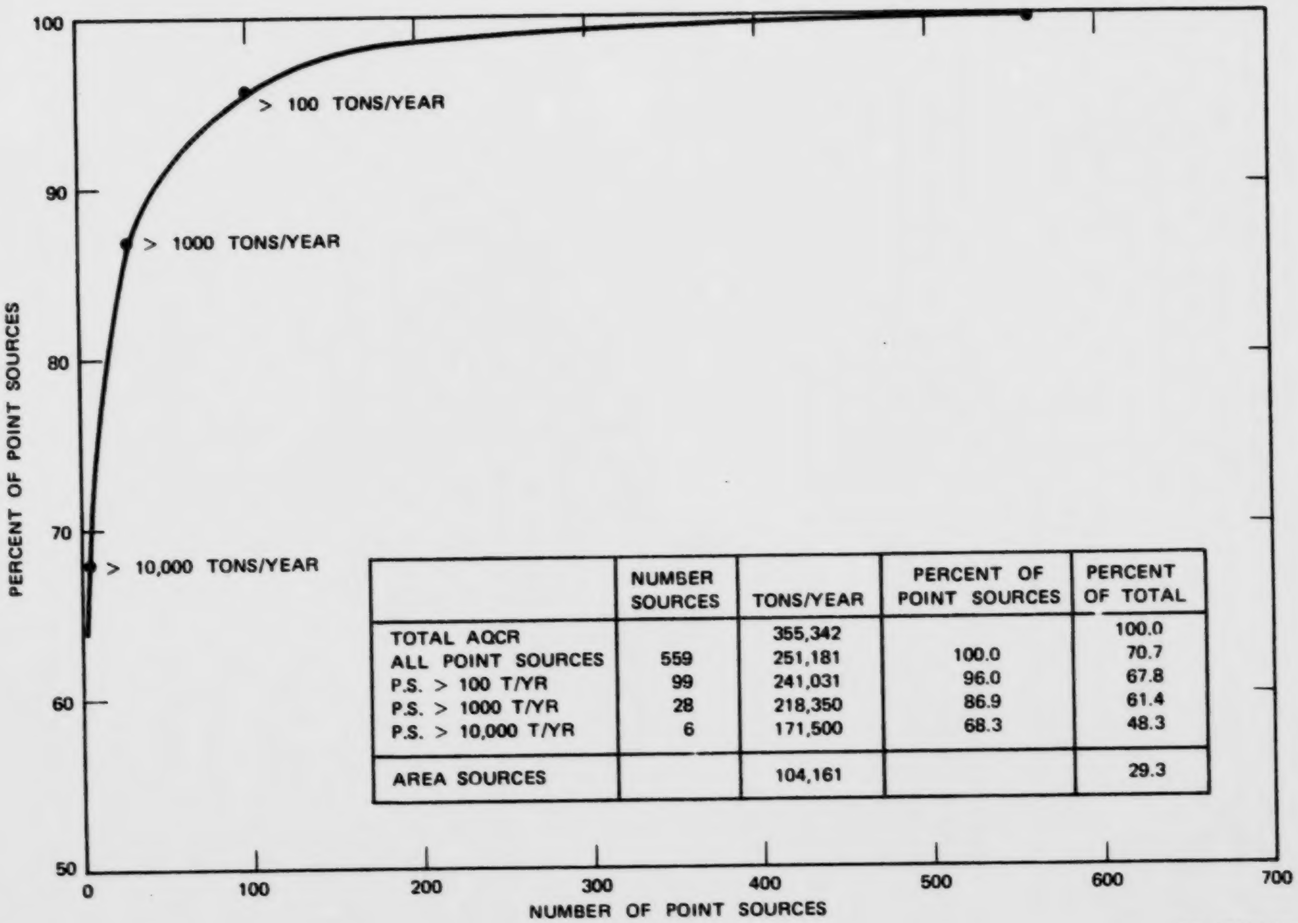
Table 19

NUMBER OF SOURCES MONITORED

Pollutant	Type of Inventory	
	90 Percent of Emissions from Point Sources	100 Tons per Year Inventory
SO_2	40	184
Particulates	50	99
CO	5	31
Hydrocarbons	99	99
NO_x	330	111

The above data can also be used to evaluate the relative importance, and thus the appropriate treatment, of area sources.

For example, if we assume that all sources emitting more than 100 tons per year of any pollutant will be monitored directly, the remaining point sources (that is, those emitting between 1 and 100 tons per year)



	NUMBER SOURCES	TONS/YEAR	PERCENT OF POINT SOURCES	PERCENT OF TOTAL
TOTAL AQCR		355,342		100.0
ALL POINT SOURCES	559	251,181	100.0	70.7
P.S. > 100 T/YR	99	241,031	96.0	67.8
P.S. > 1000 T/YR	28	218,350	86.9	61.4
P.S. > 10,000 T/YR	6	171,500	68.3	48.3
AREA SOURCES		104,161		29.3

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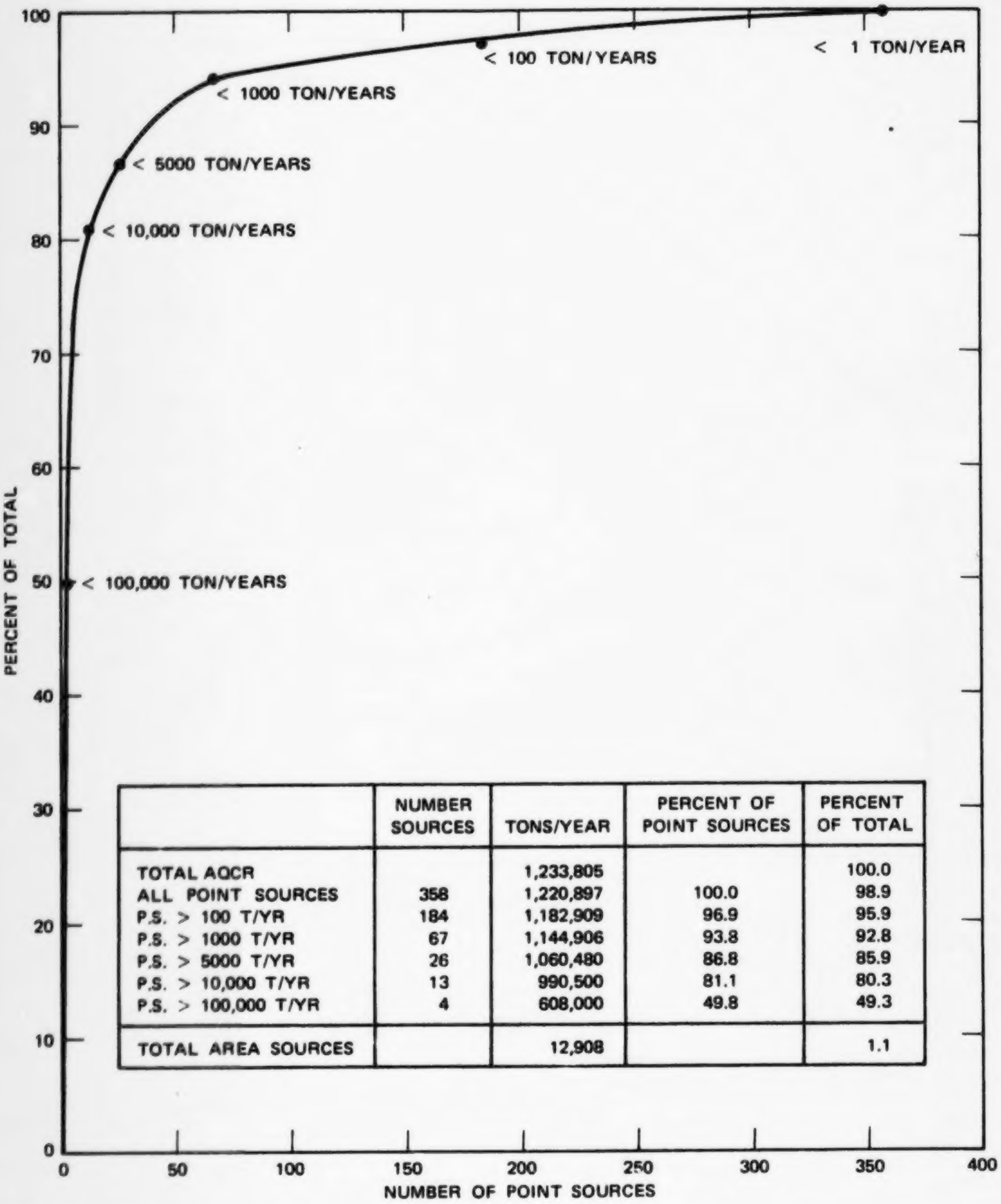
FIGURE 8 PARTICULATE EMISSIONS FOR SAINT LOUIS AIR QUALITY CONTROL REGION



	NUMBER SOURCES	TONS/YEAR	PERCENT OF POINT SOURCES	PERCENT OF TOTAL
TOTAL AQCR		1,233,805		100.0
ALL POINT SOURCES	358	1,220,897	100.0	98.9
P.S. > 100 T/YR	184	1,182,909	96.9	95.9
P.S. > 1000 T/YR	67	1,144,906	93.8	92.8
P.S. > 5000 T/YR	26	1,060,480	86.8	85.9
P.S. > 10,000 T/YR	13	990,500	81.1	80.3
P.S. > 100,000 T/YR	4	608,000	49.8	49.3
TOTAL AREA SOURCES		12,908		1.1

SOURCE: NEDS Inventory (1973).

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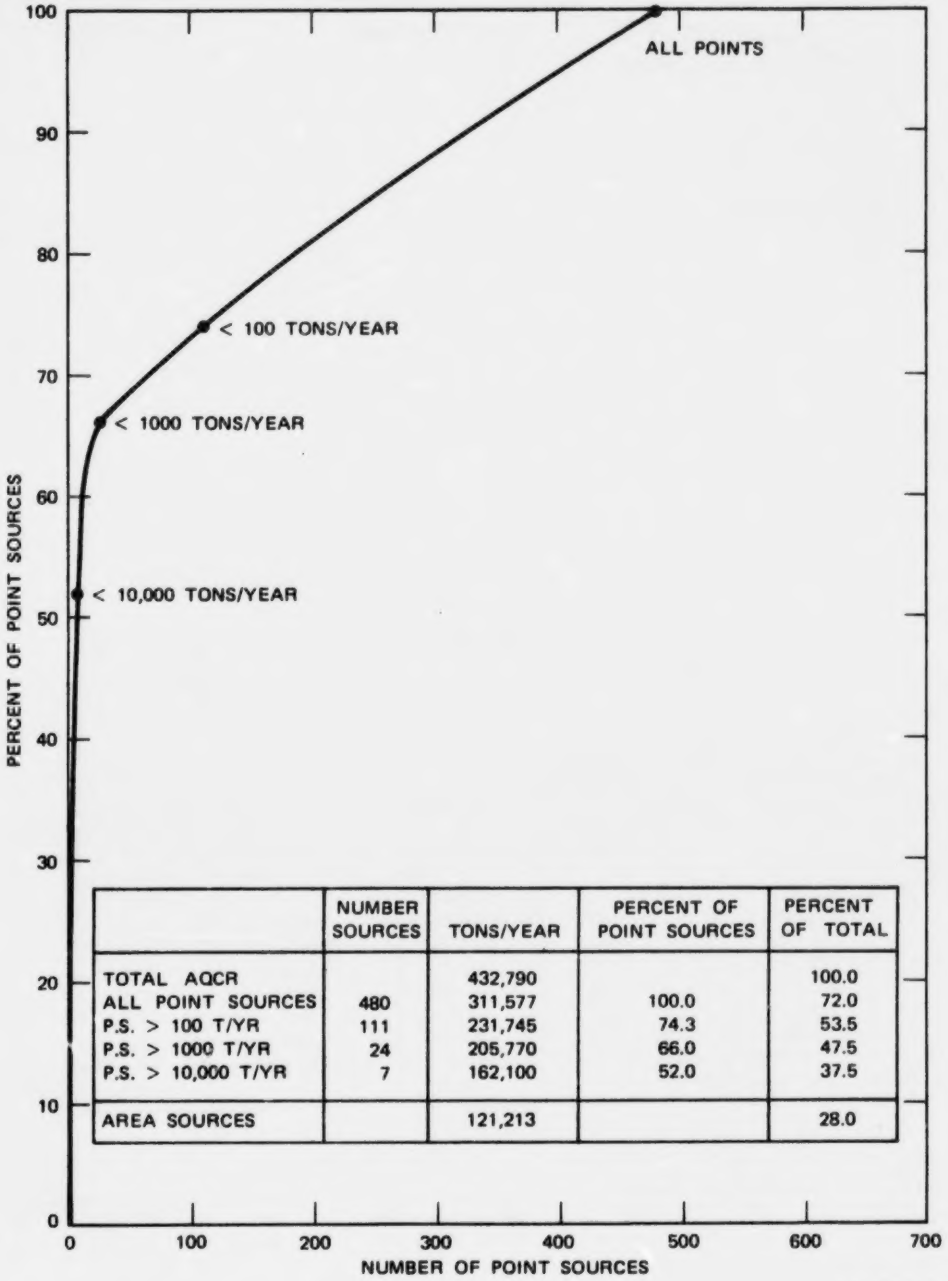
FIGURE 9 SO_2 EMISSIONS FOR THE SAINT LOUIS AIR QUALITY CONTROL REGION



	NUMBER SOURCES	TONS/YEAR	PERCENT OF POINT SOURCES	PERCENT OF TOTAL
TOTAL AQCR		432,790		100.0
ALL POINT SOURCES	480	311,577	100.0	72.0
P.S. > 100 T/YR	111	231,745	74.3	53.5
P.S. > 1000 T/YR	24	205,770	66.0	47.5
P.S. > 10,000 T/YR	7	162,100	52.0	37.5
AREA SOURCES		121,213		28.0

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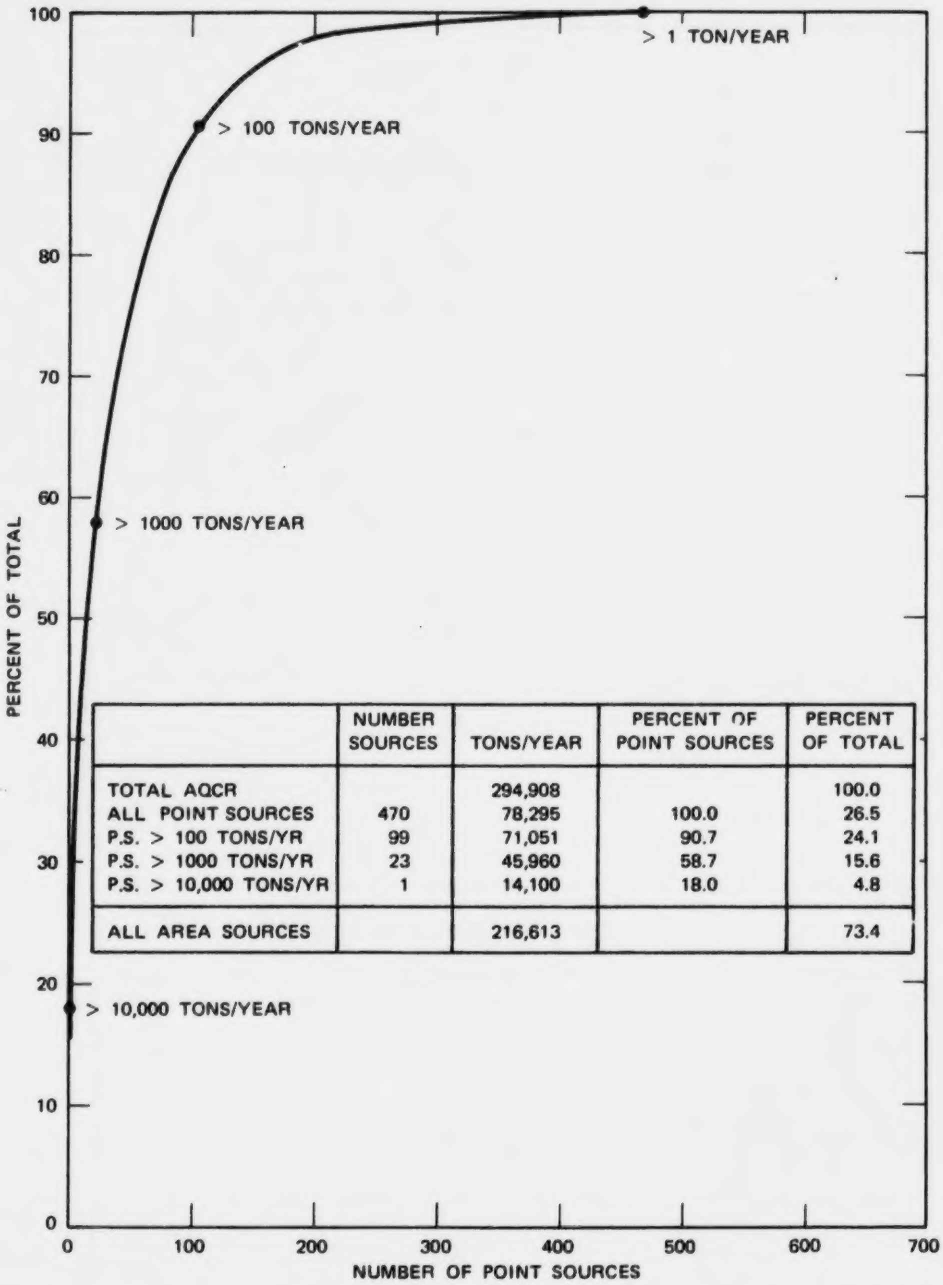
FIGURE 10 NO_x EMISSIONS FOR THE SAINT LOUIS AIR QUALITY CONTROL REGION



	NUMBER SOURCES	TONS/YEAR	PERCENT OF POINT SOURCES	PERCENT OF TOTAL
TOTAL AQCR		294,908		100.0
ALL POINT SOURCES	470	78,295	100.0	26.5
P.S. > 100 TONS/YR	99	71,051	90.7	24.1
P.S. > 1000 TONS/YR	23	45,960	58.7	15.6
P.S. > 10,000 TONS/YR	1	14,100	18.0	4.8
ALL AREA SOURCES		216,613		73.4

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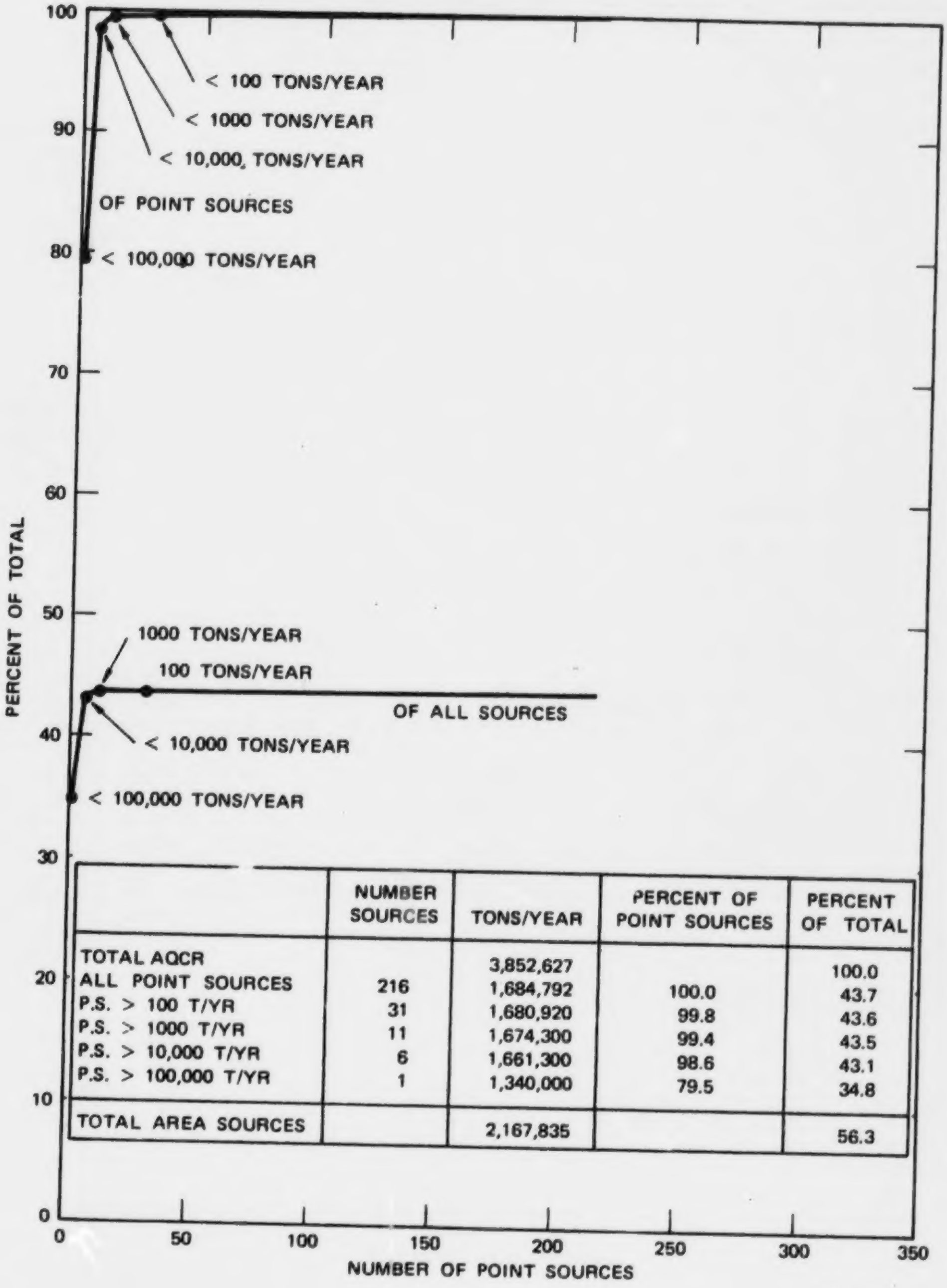
FIGURE 11 HYDROCARBON EMISSIONS FOR THE SAINT LOUIS AIR QUALITY CONTROL REGION



	NUMBER SOURCES	TONS/YEAR	PERCENT OF POINT SOURCES	PERCENT OF TOTAL
TOTAL AQCR		3,852,627		100.0
ALL POINT SOURCES	216	1,684,792	100.0	43.7
P.S. > 100 T/YR	31	1,680,920	99.8	43.6
P.S. > 1000 T/YR	11	1,674,300	99.4	43.5
P.S. > 10,000 T/YR	6	1,661,300	98.6	43.1
P.S. > 100,000 T/YR	1	1,340,000	79.5	34.8
TOTAL AREA SOURCES		2,167,835		56.3

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FIGURE 12 CO EMISSIONS FOR THE SAINT LOUIS AIR QUALITY CONTROL REGION

will be assigned to area sources. For purposes other than those of the emission inventory itself, it may be desirable to monitor directly a few point sources emitting less than 100 tons per year. Thus, a source located near an air quality monitoring station may be monitored directly to aid in evaluating the measurements from the station, and would, therefore, be treated as a point source rather than included as an area source. In addition to these minor point sources, the area sources also contain emissions of totally diffuse origin (mainly traffic, but also domestic heating). The hourly distribution patterns of these two types of sources are different. It thus becomes necessary to establish the distribution patterns of minor point sources if they amount to a significant fraction of the total area emissions.

Table 20 shows the breakdown of minor point sources in relation to diffuse area sources. The data indicate, for example, that minor point sources are an important component of area SO_2 emissions (75 percent) and small fractions of CO, hydrocarbon, and particulate emissions. On the other hand, only in the case of NO_x do minor point sources constitute an appreciable fraction (18.4 percent) of the total emissions of the Saint Louis area.

Thus, a realistic decision can be reached in the framework of actual emissions in the Saint Louis area.

C. Traffic and Transportation Inventories

1. Streets and Highways

A comprehensive study of surface transportation in the Saint Louis area was initiated in 1965 by the East-West Gateway Coordinating Council in cooperation with the State Highway Commission of Missouri, the Illinois Department of Transportation, and related federal and local agencies. The purpose of the study was to develop a balanced, multimodal transportation plan for the period extending to 1990 based on forecasts of socioeconomic and land use data.

As part of this program, traffic volume data were gathered and appropriate traffic maps were prepared. Average daily traffic counts were obtained for all major streets and highways in the City of Saint Louis, Saint Louis County, and portions of Saint Charles, Franklin, and Jefferson Counties in Missouri and Madison, Monroe, and Saint Clair Counties in Illinois. The following functional definitions were used for classification purposes:

Table 20

BREAKDOWN OF AREA SOURCES

	Number	Emissions (tons/year)	Percent of Point Sources	Percent of All Sources	Remaining Point Sources as Percent of Area Sources
SO_2					
Remaining point sources > 1 ton/year	174	37,988	3.1%	3.1%	75 %
Area sources		12,908		1.1	
Total		50,876		4.1%	
CO					
Point sources > 1 ton/year	185	3,872	0.2%	0.1%	0.2%
Area sources		2,167,835		56.3	
Total		2,171,707		56.4%	
NO_x					
Point sources > 1 ton/year	369	79,832	25.6%	18.4%	39.6%
Area sources		121,213		28.0	
Total		201,245		46.5%	
HC					
Point sources > 1 ton/year	371	7,244	9.2%	2.5%	3.3%
Area sources		216,613		73.4	
Total		223,857		75.9%	
Particulates					
Point source > 1 ton/year	460	10,150	4.0%	2.9%	9.0%
Area sources > 1 ton/year		104,161		29.3	
Total		114,311		32.2%	

- Freeways and expressways are high-volume, high-speed highways designed to carry about 12,000 vehicles per lane per day at speeds of 35 to 50 miles per hour. All cross traffic is carried on separate levels, and there are no traffic signals.
- Principal arterials carry large volumes of traffic between different parts of the urban system and connect to the freeway system. Typically, they carry 6,000 vehicles per lane per day at average speeds of 25 to 35 miles per hour. Minor arterials carry traffic between the principal arterial network; they also serve as local streets. They frequently carry up to 6,000 vehicles per lane per day at speeds of 20 to 30 miles per hour.
- Local streets provide access to all areas. They vary in design capacity.

Data were gathered for all freeways and major and minor arterials. Street names were alphabetized, and segments were designated by intersections (not by UTM coordinates). The resulting data are shown graphically on a traffic map in Figure 13, and they are updated yearly by the Missouri and Illinois traffic authorities.

2. Railways and Vessels

The U.S. Department of Transportation is planning three transportation studies in the Saint Louis area, as a part of the Saint Louis Air Pollution Studies. The goal of these studies is to ascertain the air pollution attributable to railways and vessels in addition to quantifying the emissions from specific transportation systems and facilities. The studies are being coordinated with EPA's Regional Air Pollution Study.

The first of these studies deals with waterborne vessels, which constitute a portion of the mobile pollution sources of the Saint Louis area. A comprehensive listing of sources, such as tugboats, tankers, recreational vessels, and so forth, will be organized by engine horsepower. The frequency of usage will be determined, and the pollutant emission calculated using appropriate emission factors. If the data appear to warrant additional investigation, increasingly accurate inventories are planned according to the scheme shown in Table 21.

A similar study is planned for rail operations in the Saint Louis area. Rail activity in the region has been studied for many years. The Transportation Systems Center, DoT, recently estimated annual surface

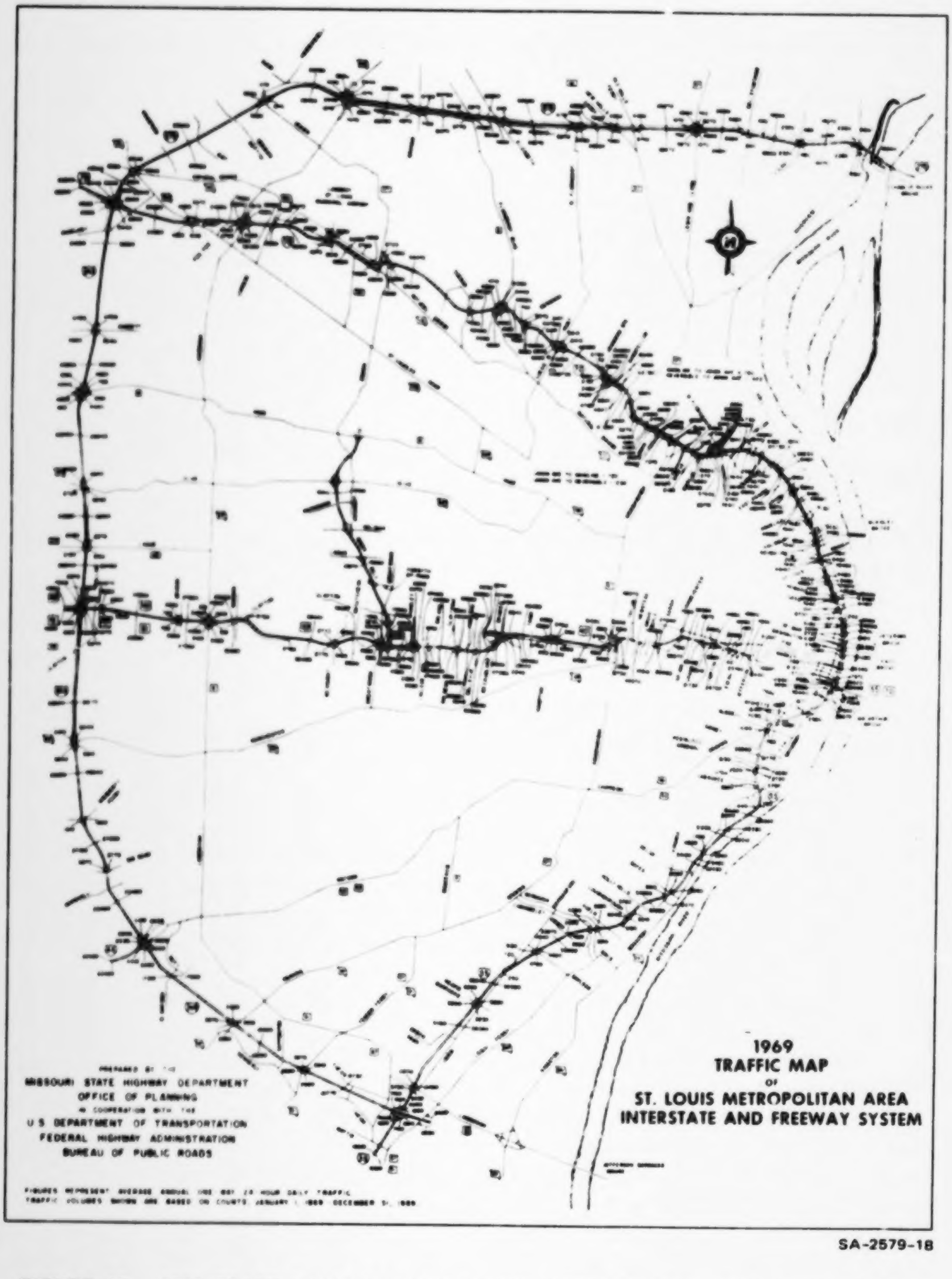
1969
TRAFFIC MAP
OF
ST. LOUIS METROPOLITAN AREA
INTERSTATE AND FREEWAY SYSTEM
PREPARED BY THE
MISSOURI STATE HIGHWAY DEPARTMENT
OFFICE OF PLANNING
IN COOPERATION WITH THE
U S DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
BUREAU OF PUBLIC ROADS
FIGURES REPRESENT AVERAGE ANNUAL 1969 24 HOUR DAILY TRAFFIC
TRAFFIC VOLUMES SHOWN ARE BASED ON COUNTS JANUARY 1, 1969 DECEMBER 31, 1969

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FIGURE 13 1969 TRAFFIC MAP OF SAINT LOUIS METROPOLITAN AREA INTERSTATE AND FREEWAY SYSTEM

Table 21

CLASSIFICATION OF POSSIBLE EMISSION INVENTORIES*

Type Inventory	Source Description	Position Resolution	Time Resolution
Based on published data	Exhaust averages from literature	Region	Yearly average
Rapid survey	Exhaust averages calculated from operators duty cycles	Terminals Mainlines	Weekly/daily average
Comprehensive	Exhaust and evaporative averages from tests	Fine grid	Weekly average and possible daily maximums
Extensive field survey	Individual exhaust and evaporative tests	Fine grid	Weekly averages and possible hourly maximums

*Source: "Air Pollution Guidelines," NATO Committee on Challenges of Modern Societies (1971).

Table 22

1967 EMISSIONS FROM RAIL OPERATIONS
WITHIN 100 MILES OF SAINT LOUIS

Pollutant	10^3 lb
Particulates	97
SO_2	253
CO	273
HC	195
NO_x	292
Aldehydes	16
Organic acids	27
Total	1,153

Source: J. C. Sturm, "Railroads and Air Pollution: A Perspective," Report No. FRA-RT-73-33, U.S. D.O.T. Federal Railroad Administration, Washington, D.C. (May 1973).

freight transportation exhaust emissions within 100 miles of Saint Louis. These estimated rail exhaust emissions for 1967 are shown in Table 22.

The rail source emission inventory will describe

- The quantity of emissions by source type
- The location of the sources
- The time pattern.

As in the case of the vessel inventory, a series of inventory methodologies will be used (similar to the ones shown in Table 21) starting with a review of published data on rail operations and standard emission factors. Subsequent inventories with increasing refinements in location, emission, and time factors are planned for those pollutants whose emissions appear to be of sufficient magnitude to warrant further investigation.

A separate study of emissions from Saint Louis railway terminals is also planned. This study will concern itself not only with emissions from locomotives, but also with emissions from stationary sources at terminals, such as power plants, fuel storage, incinerators, and with operational factors, such as freight handling by trucks or cargo spillage.

D. Summary

The requirements of accuracy and spatial and temporal resolution that the RAPS emission inventory should exhibit are not met by any of the existing inventories. The first four inventories--the IPP, IBM, DAQED, and NATO emission inventories--are essentially of only historical interest.

The NEDS inventory contains the best current estimates, and it constitutes a useful data base for those emission sources that, for practical reasons, cannot be individually measured or closely simulated by emission modeling. It can serve as a base for the determination of the scope of the task, since it details the source size and the descriptions of location, normal operating schedule, source classification code number, and stack parameters.

It certainly could meet the requirement for long-term data on a wide range of pollutants. For model verification purposes for a limited range of pollutants, the content of the NEDS inventory is, however, inadequate since it only gives annual emission data and does not provide sufficiently detailed information for the determination of hourly emissions of sufficient precision even with the application of appropriate models.

Data on traffic and transportation are in part contained in the area source emission data of NEDS. For freeways and major arteries, which will be treated as line sources, these data will have to be supplemented by information on the traffic mix, average speed, type of roadway, and other factors.

VII TASK E: EMISSIONS MODELING

A. Introduction

The specification of the rate and distribution of emissions is basic to any air quality simulation model. However, emissions per se have rarely been measured in modeling studies conducted prior to RAPS; usually, emissions are parameterized on the basis of available emissions-related data. The so-called emissions model is thus a methodology that relates available data to the required mass flux density of pollutant emissions.

Depending on the type of the emissions source and the requirements of the various air quality simulation models, emission models are conveniently classified according to the mobility and configuration and type of the source. Figure 14 is a three-dimensional matrix illustrating some 64 possible combinations of emission features that describe various emission model types. These are only broad classifications, and the number of real possibilities is considerably greater. Referring to the discussion of Task B, for example, we note that there are at least four major categories of gaseous pollutants to be considered: carbon monoxide (CO), oxides of nitrogen (NO_x), hydrocarbons (HC), and sulphur oxides (SO_x). Also, particulates may need to be classed as large ($> 2\mu m$) or small ($\leq 2\mu m$), while mobile surface emissions can be subdivided similarly as gasoline and diesel powered roadway vehicles, trains, on-ground aircraft, and so forth. The saving factors are that not all combinations exist in the real world, some are of no major concern, and others can be grouped and treated in a single approach.

Other constraints also limit the task of specifying the input requirements and the structure of emission models likely to be required in the RAPS. Many such constraining factors have already been discussed in other task reports. Emission model requirements are determined by the specific requirements of simulation models to be evaluated in RAPS. For example, the minimum emission-time resolution for most model applications is specified as one hour. (We do consider, later in this section, subhourly specifications for vehicular emissions.) Spatial resolution has also been addressed in Task B (Section IV), but an objective methodology for evaluating the required geographical resolution of major point sources is presented in this task report.

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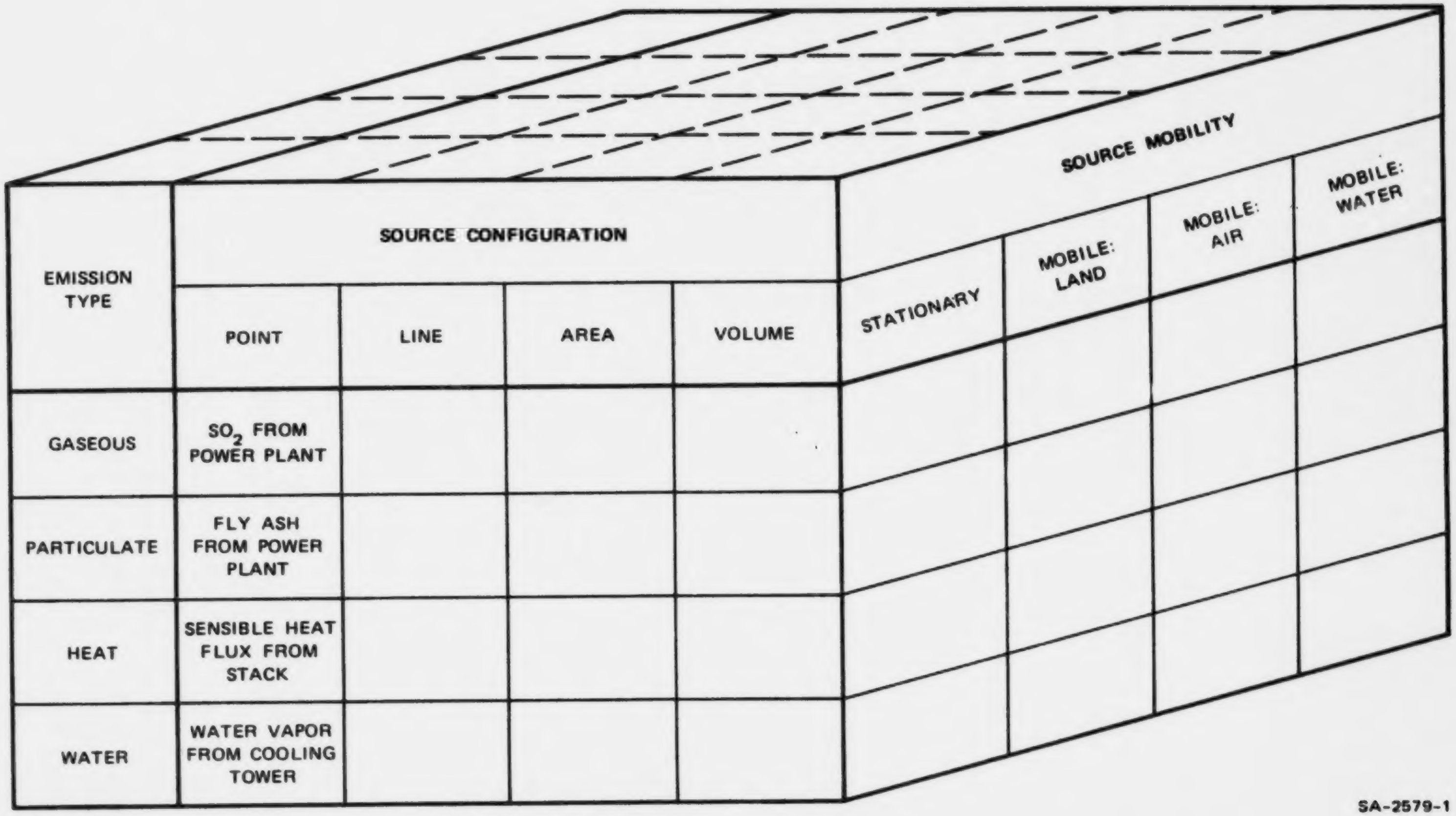
SOURCE CONFIGURATION
SOURCE MOBILITY
EMISSION TYPE
POINT
LINE
AREA
VOLUME
STATIONARY
MOBILE: LAND
MOBILE: AIR
MOBILE: WATER
GASEOUS
SO_2 FROM POWER PLANT
PARTICULATE
FLY ASH FROM POWER PLANT
HEAT
SENSIBLE HEAT FLUX FROM STACK
WATER
WATER VAPOR FROM COOLING TOWER

SA-2579-1

FIGURE 14 SCHEMATIC ILLUSTRATION OF CLASSIFICATION MATRIX FOR EMISSION MODELS

B. Modeling

1. Review of Existing Models

An extensive and in-depth review of the available literature on emissions modeling resulted in the identification of 28 papers and reports deemed significant in the context of this RAPS study. Appendix B summarizes these models by listing (1) the author's abstract, (2) our summary of the significant features of the models, and (3) the form and availability of documentation. Table 23 lists the models reviewed and summarizes the models according to emissions type, source mobility and configuration, and the degree of experimental verification. The last aspect is particularly important to RAPS where appropriate short-term specification of emissions is essential to the overall evaluation of air quality simulation model performance. In this regard, it is significant that only three of the 28 models reviewed have undergone independent experimental evaluation of the emission estimates.

While Table 23 provides an overview of the emission models, Table 24 lists details of the input requirements and outputs of selected emission models. Generally, these models are the more comprehensive ones reviewed; as such, they reflect the state of the art and outline the facility and process parameters needed to simulate emissions from the smaller sources (discussed under Task B). In Table 24, the input requirements of the various models surveyed are subdivided into model inputs and model parameters, two categories with subtle distinctions. The attempt was to list as model parameters those data that are essentially internal to the emission model in that they are usually specified only initially. Of course, they may need to be revised periodically as updated or more representative values become available. Model inputs on the other hand encompass operational inputs required to actually run the model and generate emission rates. The classification system should not be viewed as rigid or formal, but rather as a convenience.

The discussion in Section IV points out many of the inadequacies of emission modeling techniques for use in a research program focused on the development and evaluation of air quality simulation models. In the past, emission data have been derived primarily from long-term average emission estimates--especially for the stationary sources. In turn, most of the long-term data have been derived not from direct measurement, but, by applying emission factors to survey information (e.g., fuel consumption). Hourly emission estimates (and finer spatial resolution) have then usually been derived from simulation techniques surveyed in this review. The resulting aggregation of emission factors and correlation and algorithms

Table 23

SUMMARY OF CONTENT OF EMISSIONS MODELS REVIEWED

Section Number in Appendix B	Emissions Model	Emissions Type				Source							Field Evaluation			
						Stationary			Mobile							
									Surface		Aerial					
		Gaseous	Particulate	Heat	Water	Point	Area	Volume	Line	Area	Line	Area	None	Minimal	Moderate	Extensive
I	Argonne National Laboratory	X		X		X	X						X			
II	Argonne National Laboratory	X								X			X			
III	ESSA	X					X								X	
IV	Federal Highway Administration	X							X					X		
V	Free University of Berlin	X				X	X						X			
VI	General Electric	X							X					X		
VII	General Research Corporation	X				X	X			X		X	X			
VIII	Geomet	X		X		X	X						X			
IX	IBM	X				X	X						X			
X	IBM	X				X	X								X	
XI	Metropolitan Washington Council of Governments	X								X			X			
XII	NAPCA						X									
XIII	NAPCA	X								X			X			
XIV	Northern Research and Engineering	X	X							X		X		X		
XV	Ontario Department of Environment	X	X			X	X		X	X			X			
XVI	Pacific Environmental Services	X				X	X			X			X			
XVII	Rutgers University	X	X							X		X	X			
XVIII	Sacramento Regional Area Planning Commission	X	X				X			X		X	X			
XIX	Stanford Research Institute	X							X	X					X	
XX	Stanford Research Institute	X							X				X			
XXI	Stanford Research Institute	X							X					X		
XXII	Systems Applications, Inc.	X					X	X		X		X	X			
XXIII	Systems Development Corporation	X				X	X			X		X	X			
XXIV	Travelers Research Corporation	X				X	X						X			
XXV	TRW	X								X						
XXVI	University of Alaska				X	X	X		X				X			
XXVII	University of California, Davis	X								X			X			
XXVIII	U.S. Weather Bureau	X				X	X						X			

Table 24

EMISSIONS MODELS INPUT-OUTPUT SPECIFICATIONS

Model	Model Output	Source	Model Input	Model Parameters
Argonne (See Reference 2)	Hourly SO_2	One square mile area (residential/commercial/institutional)	Hourly average temperature Hour of day	Annual SO_2 emissions Fraction of annual fuel used for hot water Hours that heating cycle begins and ends Average number of degree days per year
	Hourly SO_2 and thermal emission rate	Power plants	Average daily temperature Hour of day Day of Week Month of year	Average annual percent coal used Average annual percent oil used Percent sulfur of coal Percent sulfur of oil Graph of peak load versus temperature by season Weekday and weekend seasonal graphs of system load versus hour of day Individual unit loads versus system load for each unit Thermal input versus unit load
	Hourly SO_2 and thermal emission rate	Industrial point sources	Average daily temperature Shift Day of week Month of year	Maximum space-heating thermal load Maximum process load Average annual percent coal used Average annual percent oil used Percent sulfur of coal Percent sulfur of oil Shift weighting factors Monthly fuel use weighting factors
Geomet (See Reference 5)	2-hourly SO_2 (See Reference 17 for description of this method.)	Industrial point sources	Hour of day Day of week Hourly temperature	Peak process SO_2 emission rate Annual number of degree days Annual fuel usage by type SO_2 emitted per unit fuel consumption (by type) Daily average fraction of peak process emission rate Winter season degree days Fraction of annual fuel usage in winter Commercial fuel usage correction factor
	2-hourly SO_2 and stack volume flow rate	Power plants	Hour of day Power output for the hour	Peak power output SO_2 emission factor Percent sulfur of fuel Fuel flow rate versus power output Stack volume flow rate versus power output

Table 24 (Continued)

Model	Model Output	Source	Model Input	Model Parameters
Geomet (continued)	2-hourly SO_2	Area sources (5,000 square feet) (residental/commercial institutional)	Hour of day Hourly temperature Number of fuels used	Summer day fuel consumption as a fraction of average winter day Average winter degree day Duration of season SO_2 emission per unit fuel (by type) Number of commercial sources Fraction of annual quantity of fuel (by type) used in summer season Annual quantity of fuel used (by type) Average number of rooms per dwelling unit Number of residential dwelling units using various fuel types Average annual U.S. household space Heating energy requirement - units Average number of rooms per U.S. household Average annual U.S. degree days Heating efficiency of fuel (by type) Commercial diurnal variation factor Winter season degree days Fraction of annual quantity of fuel (by type) used in winter season River vessel SO_2 emission rate Base automotive SO_2 emission rate Diurnal automotive variation factor Railroad SO_2 emission rate Backyard burning SO_2 emission rate Number of industrial sources Base industrial process emission rate Industrial day-of-week variation factor Industrial diurnal variation factor Residential fuel usage correction factor Commercial fuel usage correction factor
	Hourly SO_2 (See Reference 2 for description of method)	Area sources (one square mile) (commercial and residential)	Hourly average temperature Hour of day	Annual SO_2 emission Fraction of fuel usage for hot water heating Annual number of degree days Diurnal fuel usage factor Hours fuel usage per day Commercial temperature correction factor Residential temperature correction factor

Table 24 (Continued)

Model	Model Output	Source	Model Input	Model Parameters
Geomet (continued)		Power plants Same input and output as in Reference 1 except algorithm directly apportions emissions to individual stacks and thus requires fraction of emissions from ith unit going to jth stack Industrial point sources As above, except require additionally fraction of emissions going to jth stack		
IBM (See Reference 18)	2-hourly SO_2	Area sources (space and hot water heating)	Daily mean temperature Hour of day	Annual SO_2 output Average annual degree days Fraction of sources due to hot water heating Fraction of sources due to space heating Diurnal emission variations Total number of area sources Number of different area source sizes used Number of area source grids in each area source size Number of rectangular regions for entire source grid x, y coordinates denoting limits of regions and size of source grid for that region
NAPCA (See Reference 17)	2-hourly gas and steam send-out	Space heating sources	Hour of day Day of week Hourly temperature (ambient)	Usage factors for gas and steam by hour of day and day of week (generated by model) Regression constants from daily steam (or gas) output rate by daily temperature
Ontario Department of the Environment (1971)	Hourly CO, NO_x, and HC from automotive by one square kilometer areas	Area sources for one square kilometer Automotive emissions	Roadway class Hour of day Day of week Season of year	Vehicle count per day per grid square Road length in each grid square Emission factors Diurnal factors (speed and volume) Daily factors (volume) Seasonal factors (volume)
	Hourly SO_2, NO_x, CO, HC, and particulates by one square kilometer areas	Shipping, railroads, aircraft, gasoline storage, apartments, schools and universities, industrial, commercial, public buildings, and residential emissions	Average daily temperature Hour of day Day of week Season of year	Annual emissions Diurnal emission factors Daily emission factors Seasonal emission factors Annual number of degree days Dwelling type Fuel type

Table 24 (Continued)

Model	Model Output	Source	Model Input	Model Parameters
Ontario Department of the Environment (continued)	Hourly SO_2, NO_x, HC, and particulates for point sources greater than 100 pounds per day	Point sources - emissions greater than 100 pounds per day	Average daily temperature Hour of day Day of week Season of year Shift	Annual emissions Diurnal factors Daily factors Seasonal factors Annual number of degree days Space heating correction factor Fuel type
SAI (See References 1 and 3)	Hourly NO_x, CO, and hydrocarbons	Area sources for two square miles Automotive emissions - exhaust	Day of week Minute of day	Fraction of vehicle registration that are autos Emission rates from trucks and buses Distribution of vehicle trip-start times Ratio of cold-start to total starts during time intervals Emissions from a vehicle during a time interval after a cold-start Emissions from a vehicle during a time interval after a hot-start Average emission rate by pollutant from an auto over period between 7-1/2 and 22-1/2 minutes after a cold-start Average emission rate by pollutant from an auto over period between zero and 7-1/2 minutes after a cold-start Fraction of daily nonfreeway traffic count assignable to hourly period Nonfreeway vehicle mileage per day Average speed in fast and slow directions Coefficients from average speed and hot running emissions rate, by pollutant Diurnal factors for freeway traffic counts Freeway vehicle mileage per day Traffic counts as a function of time for selected streets to give ratio of vehicle miles driven in fast and slow directions Federal driving cycle (FDC) hot-start emission factors FDC cold-start emission factors
	Hydrocarbons (g/mi)	Automotive emissions, blow-by		Blow-by emission rates, by auto year and type (controlled or uncontrolled) Registration figures by auto year and type
	Hourly hydrocarbons	Automotive emissions, evaporative	Hour of day	Average daily tank and carburetor evaporation losses Number of automobiles in area Total nonfreeway vehicle mileage Distribution of nonfreeway vehicle miles per day

Table 24 (Continued)

Model	Model Output	Source	Model Input	Model Parameters
SAI (continued)	Hourly CO, NO, NO_2, and hydrocarbons	Aircraft emissions, ground operations	Hour of day	Diurnal distribution of total daily flights Fraction of airport area belonging to a particular grid square Number of flights per day for each aircraft class Average number of engines for each aircraft class Pounds of each pollutant per 100 pounds fuel for each class operating in each mode Pounds of fuel consumed per engine of each class operating in each mode
	Hourly CO, NO, NO_2, and hydrocarbons	Aircraft emissions, flight operations	Hour of day	Diurnal distribution of total daily flights Number of flights per day for each aircraft class Average number of engines for each aircraft class Time spent in descent from inversion height to touchdown, by aircraft class Time spent in descent from 3000 feet above ground to touchdown, by aircraft class Pounds of fuel consumed per engine during descent from 3000 feet, by aircraft class Fraction of length of flight path assignable to each cell Molecular weight of pollutant Volume of cell Molal volume of an ideal gas at one atmosphere and 60°F
	Hourly NO_x and low and high reactivity organic gases	Oil refineries	Crude capacity of refinery	Total daily refinery emissions for each pollutant Proportionality factors for crude refinery capacity
	Hourly NO_x	Petroleum marketing, domestic, ship and railroad emissions	Hour of day	Daily emissions from each source Population density distribution
	Hourly NO_x	Incineration, mineral processing, metallurgical plants, petroleum production (five square miles)	Hour of day	Total daily emissions Spatial distribution of ratios of permits issued in an area to total permits issued
	Hourly NO_x	Other industries	Hour of day	Total daily emissions Population density distribution
	Hourly organic gases	Petroleum marketing, dry cleaning, degreasing and other uses of organic solvent	Hour of day	Total daily emissions Population density distribution
	Hourly organic gases	Surface painting and coating operations	Hour of day	Total daily emissions Spatial distribution of ratios of permits issued in an area to total permits issued
	Hourly organic gases	Petroleum production		Total daily emissions Spatial distribution of ratios of permits issued in an area to total permits issued

Table 24 (Concluded)

Model	Model Output	Source	Model Input	Model Parameters
SAI (continued)	Plume rise	Volume sources Power plants	Season of year Hourly emissions	Wind speed Heat emissions from stack Average wind speed at stack height Average density of ambient air Specific heat of air at constant pressure Temperature differences between top and bottom of inversion Temperature of ambient air
SRI (See Reference 4)	Hourly CO	By link vehicular emissions	Link volume Facility type or average speed on link Time of day	Emission factors Diurnal factors Link distance End of link (node) coordinates
SRI (See Reference 19)	CO, HC	By link vehicular emissions	Link volume Operation mode Time resolution	Emission factors Calendar year Link distance Link capacity
TRW	Hourly CO, HC, NO_x	Vehicular emissions per one mile grid	Time of day	Emission factors Vehicle miles traveled, by grid Average speed for links in grid
University of Alaska (See Reference 20)	Gross aqueous emissions	Gasoline, coal and fuel oil combustion sources	Consumption	Fuel type Water content
		Cooling ponds		Temperature gradient (pond) Pond open area Conductivity Surface water temperature Air temperature regime Cloud cover
		Sewage treatment, open mines, people and animals breathing		
Northern Research and Engineering (1971)	Hourly SO_2, NO_x, CO, HC, and particulates	Aircraft	Type of aircraft Frequency of aircraft operations (landing and takeoff) Operating mode (idle, taxi, takeoff, landing)	Aircraft emission rate by operating mode and by aircraft type
		Aircraft ground support equipment	Type of equipment Operating time per hour	Emission rate by equipment type
		Space heating of terminal	Btu required or fuel consumed per hour	Emission rate per Btu generated or fuel consumed
		Vehicles within airport boundary	Types of vehicles Number of passengers Passenger load factors Operating time per hour	Emission rate by vehicle type

for the simulation of high resolution spatial and temporal emissions is, thus, defined as the emission model. Because of the uncertainties and potential for error in these methods, an emission inventory system for RAPS that relies heavily on measurement techniques has been proposed. However, two areas have been identified where the measurement approach is not feasible and where the use of simulation techniques is recommended. As discussed in Section IV, small stationary sources fall into this category. And it will be shown here that the magnitude of the mobile emission (i.e., roadway emission) network requires the use of emission simulation techniques together with some special measurements.

In spite of the limitations of many of the emission models, we have sought to identify those models that are appropriate to the treatment of small stationary sources and mobile sources. We have also included models that have heretofore been used to simulate emissions from the larger point sources; without the special, direct measurements recommended in Section IV, these models would provide the best (though admittedly coarse) emission estimates for these sources. Having thus placed in perspective the role of emission models in RAPS, we discuss below a cross section of models and the needs they appear to serve.

- The Argonne Model of Roberts[2]* for the simulation of hourly SO_2 emissions from distributed residential, commercial, and institutional sources, and for hourly SO_2 and thermal emissions from major point sources.
- The emissions model developed at Systems Applications, Inc. (SAI), by Roberts[1,3] for hourly stationary point and area source emissions of NO_x and hydrocarbons. This model is also recommended for the simulation of vehicular NO_x, CO, and hydrocarbon emissions subject to one reservation. The SAI aggregates vehicular emissions into two square mile area sources--a feature that may be too gross for direct application to RAPS. Therefore, we suggest that the SAI model be modified to provide link-by-link emissions for the major links in the manner of the Stanford Research Institute (SRI) model of Ludwig[4] while retaining the spatial averaging (on the smaller scale of one square kilometer) method for the secondary links.

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*Model reports are reviewed in Appendix B.

- The Geomet model[5] for diurnal emissions from river vessels and railroads.
- The Platt's model for Northern Research and Engineering,[6]* for aircraft emissions.

Several categories of emissions are notable by their absence from the above listing. To the best of our knowledge, there are no models available that treat heat emissions from vehicular or distributed area sources although the inputs to such models already seem to be required in the SAI, SRI, Geomet, and Argonne models. However, appropriate thermal emission factors are required. Another shortcoming of the available models is the treatment of particulate emissions. While four of the 28 models reviewed treat particulates, none provides output on size distribution.

Furthermore, very little has been done to develop a regionally applicable model of man-induced water vapor emissions. To be sure, the knowledge and expertise are available to develop such a model, but a rigorous and comprehensive methodology has not been compiled. Perhaps the closest facsimile to what is required is the work at the University of Alaska by Benson[20] for Fairbanks, Alaska, where water is considered a primary atmospheric pollutant in winter. Thus, we recommend the use of an aqueous emissions model, similar to Benson's, but expanded as discussed later.

Lastly, the emissions modeling work of the Ontario Department of the Environment for Toronto is perhaps the singularly most comprehensive, available methodology; it is not, however, generally available. We suggest that official requests be submitted to the Ontario Department of the Environment since many of their methods and experiences might be of benefit in the development of the RAPS emissions inventory.

2. Specification of Emissions

The basic requirement of the RAPS emissions inventory program is to provide hour-by-hour emission rates for the various pollutants and heat and water vapor. The pollutant emissions are of primary importance

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*This model is currently being modified by Geomet under Contract 68-02-0665 with the Meteorology Laboratory, Environmental Protection Agency, Research Triangle Park, North Carolina.

(they specify the basic emission inventory requirements), while heat and water vapor can be determined from data acquired in the course of listing the pollutants (see Task B).

For stationary sources, there is a three-stage sequence in which emissions should be specified in RAPS.

(1) Direct measurement of emissions.

(2) Measurement of inputs to the pollutant-generating process with subsequent parameterization of the input-output (i.e., emissions) relationship.

(3) Parameterization of both the inputs and input-output relationship.

An example of the first would be the use of in-stack monitors at major power-generating facilities. The second method would employ measurement of process parameters directly related to emissions (e.g. fuel consumption rate). while in the third case these parameters might be determined from a statistical base or as a function of a known indirect indicator (e.g., degree-hours). Prior to RAPS, regional studies employed the third method almost exclusively. In RAPS, however, greater emphasis must be placed on the first and second methods.

a. Stationary Sources

Direct monitoring (input or output) of all stationary sources is not practicable in view of financial constraints, nor is it required; hence, there is a need for emission models. The available inventories for Saint Louis have been reviewed in discussions of Tasks B and D to identify the number and size of the major point sources of SO_x and NO_x (CO and HC are emitted primarily by distributed sources). A major point source may be considered as one that receives individual treatment in an air quality dispersion model, not one that is aggregated into an area source. About 13 point sources (e.g., power-generating plants) have been identified as "principal" major emitters with emission rates far in excess of "secondary" major point sources. As a first step, we have proposed (Task B) routine emissions monitoring for all principal sources and routine input monitoring for secondary point sources. Routine input or emissions monitoring is not required for the remaining individual stationary point and area sources. The best available emissions models will serve adequately.

The types of input or emissions measurements recommended above for various stationary sources are those necessary to provide the accurate and current emissions inventory required as input to the operation or evaluation of mesoscale air quality simulation models. Where the intent is to investigate microscale phenomena, the basic or routine inventory will need to be supplemented with special emission inputs. Depending on model receptor locations (or the location of air quality monitoring stations), it may be necessary to provide higher resolution emissions data for some of the lesser sources. Thus, for example, minor point sources near a particular receptor may either need to be monitored continuously or, at least extensively, during selected periods. More specific requirements cannot be set until actual monitoring sites are determined or specific research studies defined. This is especially true for emissions from mobile sources; further considerations along these lines are presented later in this section.

b. Mobile Sources

For routine use, the mobile emission inventory should be estimated for link or line source geometry using an average route speed model formulation such as that used in APRAC-1.[21] Links are straight segments of major arterial streets and freeways that serve as the transportation network for the area. In most urban complexes, this kind of network has about a one-half to one-mile span in suburban areas and a one-block span in downtown areas. The link geometry is recommended because it is conveniently related to the parameters needed to estimate emission, links can conveniently be aggregated into area sources (but not the reverse), and control strategies to be investigated later will deal with modifications of the locations or conditions on the links (not the areas).

The mobile emission inventory is thus envisaged to comprise three distinct elements: (1) the basic roadway network, (2) traffic characteristics, and (3) an emissions model. The first element is a listing of the characteristic features of each link in the roadway network, such as

- Link location (geographical location of the endpoints).
- Facility type (e.g., suburban freeway, downtown arterial).
- Roadway characteristics (e.g., number of lanes, grade, elevation, foundation).

Traffic characteristics are those parameters that describe the vehicle population and traffic flow. In this category, the inventory must contain data on

- Vehicle mix by age and type (e.g., numbers and ages of light duty vehicles and heavy duty diesel and gasoline-powered vehicles).
- Vehicle speed (by facility type and location).
- Distribution of origin-destination (O-D) locations.

Because vehicle emissions cannot be measured directly in situ, they need to be determined with the aid of an emissions model using traffic and roadway data in the manner of Roberts' model[2] or Ludwig's model.[4] (A number of other sources discuss the requirements and availability of roadway and traffic data.)[22,23,24,25,26] As indicated above, we recommend the use of the average-speed emissions model on a link-by-link basis as the primary mobile emissions format; in this manner, area-averaged emissions can be obtained appropriate to the dispersion model structure or individual-link data could be retained for the larger roadways for line-source models. We further suggest that O-D data be used to identify cold-start emission contributions. Lastly, a multimodal emission model should be used for individual microscale studies. But the collection of the appropriate data and the operation of the model to generate emissions data should not be a part of the basic inventory; rather it may be considered as a separate task of the individual miscroscale study. Lastly, we note that the use of multimodal models[19] is still in a preliminary stage pending the availability of emissions test data.

The average route speed model requires inputs of traffic volume on the links and link speed. Diurnal traffic factors and emission factors for the vehicle mix on the link are also parameters of the model.

There is enough similarity of utilization (volume) on most urban streets that estimates based on periodic samples, supplemented by data from fixed sensors on high-volume freeways and on selected arterial streets will serve the purpose. These periodic samples are routinely taken by the traffic department as part of monitoring the adequacy of the street system. The volume data from these surveys are expressed in average daily traffic and require a diurnal pattern to convert the daily into hourly traffic. For this reason, monitors capable of hourly or finer resolution should be installed on typical streets representative of different usages: arterials at various distances from the center of town, arterials with various functions (downtown distributor; suburban collector; shopping center, university, or airport service). These different functions may imply different diurnal variation patterns and, hence, should be monitored. In addition, fixed monitors in such places will help to determine the variation by day, week, or season; from these data, factors for similar facilities may be developed and used for the emission models.

As in the hourly variation patterns, speed (and hence emissions) vary with volume of traffic, but speed distribution will be similar from day to day. Speed data are needed for the same kinds of facilities as those described above, and both fixed and portable monitors capable of providing speed information should be used.

Special consideration should be given to the inclusion of cold-start emission effects. Martinez, Nordsieck and Eschenroeder[27] have evaluated the comparative impacts of cold- and hot-start emissions (vehicular HC, NO, and CO) for Los Angeles in the time period from 0600 to 0900. Their findings are shown in Table 25 expressed as the ratio of emissions with cold start to emissions without cold start.

Table 25

RATIO OF COLD-START EMISSIONS TO
HOT-START EMISSIONS

Species	Year			
	1968	1971	1974	1980
NO	1.15	1.16	1.16	1.01
CO	1.48	1.57	1.53	2.30
Reactive hydrocarbons	1.08	1.10	1.11	1.11

We see that the neglect of the cold-start emissions contribution would have a moderate impact on the estimation of reactive hydrocarbons and a severe impact on CO by 1980. The emission inventory must therefore provide cold-start emission factors. Martinez[27] provides values that may be used for light-duty vehicles through 1976; these are summarized in Table 26.

Table 26

COLD-START EMISSIONS FROM LIGHT-DUTY VEHICLES

Model Year	Cold-Start Emissions (gm/start)		
	NO_x (as NO_2)	HC	CO
≤ 1968	5.66	10.73	254.1
1969	6.56	9.54	143.6
1970	5.89	10.88	143.3
1971	5.36	6.18	92.53
1972	4.02	4.25	76.74
1973-74	3.78	4.25	76.74
≥ 1975	-1.04*	2.68	43.06

*The negative factor is, of course, used in conjunction with the running emission factor, thereby effectively reducing net NO_x emission.

Under special conditions, as when forecast values of air quality are compared with measured values, continuous and detailed monitoring of vehicle behavior in the immediate environment of the measurements may be required with emissions being forecast with a multimodal emission model such as Ludwig's (reviewed in Appendix B). Such monitoring would not be done area-wide or continuously, because it is not appropriate to mesoscale studies. The multimodal model contains emission factors for the standard vehicle maneuvers: steady driving, slowing and speeding, stopping, and accelerating from a stop. Hence, the resolution of the model in space can be adjusted to the location and needs of the experiment. That is, a downtown block might be divided into several links, each a few tens of meters long. Vehicle modes such as acceleration, steady driving, congested driving, or stopping, would be assigned to each link. Volume in each link would be measured on a time scale comparable with the needs of the experiment.

Special microscale studies of vehicle-generated emissions may require subhourly inputs of vehicle parameters. This is especially important when the distribution of inert pollutants in heavily traveled areas is evaluated (e.g., CO in the central business district or in the corridor of major freeways). For such situations, 15-minute resolution may be necessary. In the earlier discussion on special measurements of stationary emissions, specific details of special mobile emissions requirements must await formalization of the plans for individual research studies.

c. Water Vapor Emissions

A special aspect of the overall emissions modeling program (both for stationary and mobile sources) is the treatment of aqueous emissions. As noted earlier, a comprehensive regional model for water has not been developed although emission factors are available at various levels of refinement. For example, Benson[20] presents emission factors for water (and carbon dioxide) emissions from the combustion of gasoline, fuel oil, and coal. For gasoline and fuel oil, emissions of water are readily specified on the basis of spatial and temporal distributions of fuel consumption. These will generally be available directly from the basic inventory of the other pollutants (e.g., SO_2, CO). Two exceptions may be surface vehicles and major point sources. For the former, the link inventory will provide facility type and vehicle volume, mix, and speed information; additional factors (or submodels) will therefore be required to obtain gasoline consumption. Direct monitoring of water emissions from large point sources may not be the optimum method. Rather, grab samples as discussed in Section IV may be more appropriate both because of economies of the method and because of relative invariability of the exhaust water content. These would then be related to the more available information on fuel and process features.

The man-induced emissions of water from air conditioning (ac) units, small cooling ponds, sewage treatment plants, and so forth should be aggregated into gross composite emissions for specified areas of the order of one to two kilometers on a side. For ac units, statistical relationships based on an inventory of ac capacity and type and the ambient conditions of wind, humidity, and temperature would be adequate to estimate the corresponding emission rates. Similar procedures could be used for cooling ponds and the like; for sources of this type, the inventory should contain information on the area and volume of the ponds, input water temperature, and degree of mechanical mixing. The emission rate is then determined for the appropriate time and location using an analytical or statistical model of potential evapotranspiration.

However, rather than calculate the emissions of water from the measured or prescribed inputs, we recommend that such "meteorologically-controlled" aqueous emissions from man-induced sources be determined outside the RAPS emissions inventory. We view these sources as those in which man's activities provide the potential (i.e., a water supply) for aqueous emissions to the atmosphere but in which meteorological processes regulate the magnitude of the vapor flux. In summary, aqueous sources in this category include the following:

- Cooling ponds
- Sewage treatment ponds
- Irrigation
- Space cooling units.

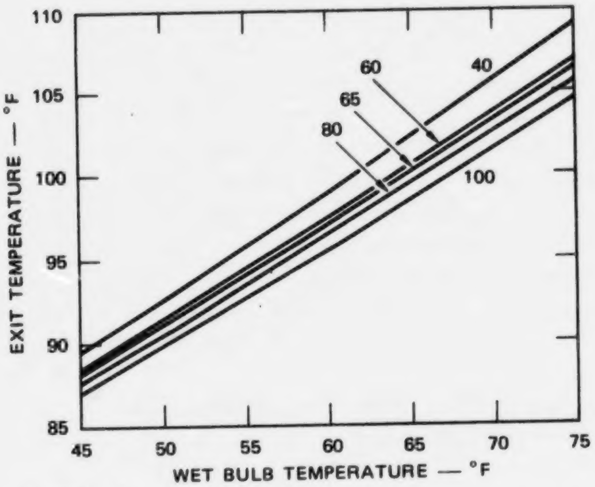
Lastly, anomalous sources of aqueous emissions, in particular, wet cooling towers with their enormous outputs of water vapor and their significant impact on visibility, gaseous reactions, and such, must be considered. For example, moisture discharge rates for very large power plants (e.g., 2,000-MW fossil steam plants) are of the order of 1.5×10^5 lb/min--a rate equivalent to the daily deposition of a 1-cm column of water on a 10-km^2 area.

To simulate these emissions accurately, the inventory should contain the design performance standards and power generation rates for each source. The environmental parameters required in the inventory are the ambient wet bulb temperature and relative humidity. Figures 15 and 16 illustrate performance curves for a natural-draft cooling tower that dissipates 8×10^9 Btu/h; note that the performance curves are also used to estimate the sensible heat output of the tower as required for the thermal emissions inventory.

3. Emissions Model Verification - Mobile Sources

In view of uncertainties in determining mobile emissions, an experimental program of emissions model verification is advocated. The uncertainties arise from imprecisions both in the specification of process input parameters and in the accuracy of the postulated input-output relationships.

Recalling previous discussions on the nature of emissions models, we may conveniently define two principal types. In one, the input (I) is known as a function of time (t), and its relationship to the emissions is



SOURCE: Bowman and Biggs, 1972.

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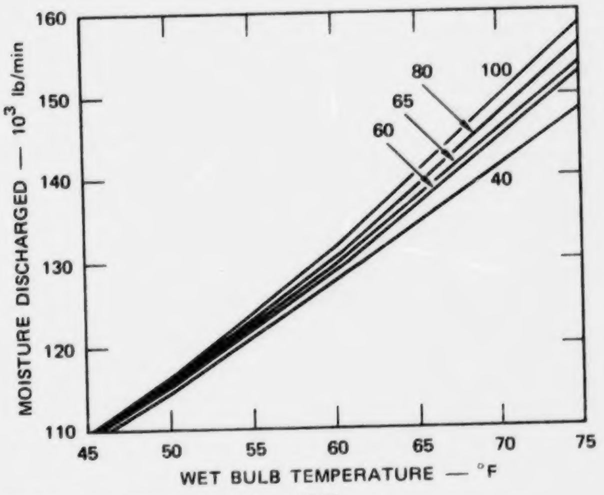
FIGURE 15 PERFORMANCE CURVES FOR COOLING TOWERS GIVING THE EXIT TEMPERATURE AS A FUNCTION OF THE AMBIENT WET BULB TEMPERATURES FOR VARIOUS EXIT RELATIVE HUMIDITIES



SOURCE: Bowman and Biggs, 1972.

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FIGURE 16 PERFORMANCE CURVES FOR COOLING TOWERS GIVING THE MOISTURE DISCHARGE AS A FUNCTION OF THE AMBIENT WET BULB TEMPERATURE FOR VARIOUS EXIT RELATIVE HUMIDITIES

specified by an input-dependent emission factor (EF); the functional form for the specification of the time-dependent emission rate E(t) is

$$E(t) = I(t) \cdot EF(I) \quad .$$

In the second type, the input rate is also unknown and, hence, a time-dependent input factor $\left(IF(t)\right)$ is also required. The emission rate for this case is then given as

$$E(t) = I \cdot IF(t) \cdot EF(I) \quad .$$

Implicit in these formulations is a knowledge of the spatial distribution of the inputs. Mobile sources (and certain stationary area sources) are especially complex in that the time-dependence of the input factor must be expressed as a function of location.

Thus the so-called emissions model may actually be composed of three components: (1) the apportionment of inputs on a temporal basis, (2) the apportionment of inputs in space, and (3) the relation of emissions to inputs. Similarly, the field (i.e., in situ) verification program also must serve to evaluate the emissions model performance in these three areas.

Parameterization of the inputs is particularly relevant to the generation of the mobile emissions. The recommended procedure is to use a statistical database (e.g., ADT) together with continuous measurements of vehicle volume, speed, and mix on selected key links to generate a dynamic link-by-link mobile inventory. Evaluation of the adequacy and representativeness of this procedure should be undertaken. Two methods appear feasible for this purpose: (1) aerial photography, and (2) side-looking aerial radar. The first method could easily provide spatial inventories of vehicle volume and mix by facility type, location, and time of day; less easily obtainable, although possible, is the determination of vehicle speeds. The second method can provide volume and speed distributions, but not vehicle mix. Again, these evaluations are recommended for selected hours, days, and seasons; we do not advocate continuous usage of either method throughout RAPS.

A similar but less difficult problem is the parameterization of temporal and spatial variations of fuel consumption by distributed area sources.

For mobile sources, it is advisable to evaluate parameterization of the inputs and outputs separately; we have already discussed treatment of the former for vehicular sources. For the latter, it remains to verify the representation of time-averaged emissions on a per-link basis. Both average speed and multimodal emission factors can be used, and both are based on emissions during the federal driving cycle (FDC). What is not known are the impacts of deterioration, mix, road grade, drag, and so forth. Model evaluation studies should be undertaken to evaluate the simulation of emissions on a variety of link types (such as freeways, expressways, major arterials, and local feeders) in congested areas. Accurate link measurements of vehicle inputs--volume, mix, speed, and acceleration--will be necessary. Emissions should be determined as averages for 15-minute intervals for all vehicles on the link. A mass budget approach seems most appropriate for this purpose.[28,30] The concept of the mass budget approach is simple, yet its implementation in the field can be difficult--especially when accuracies of 10 to 20 percent are required (see Task B). Simply stated, the fluxes of effluvia into and out of a control volume are measured, and the net flux is equal to the pollutant source or sink within the volume. For the horizontally homogeneous, height-dependent wind field u(z), the mass flux density Q(gm m^{-1} sec^{-1}) through a control volume having zero vertical flux through the top (H) is given by

$$Q = \int_0^H \chi_1(z)u(z)dz - \int_0^H \chi_2(z)u(z)dz \quad .$$

Here, $\chi(z)$ is the height-dependent pollutant concentration; the subscripts 1 and 2 refer to the upwind location and the downwind location. Thus, determination of the mass flux density (i.e., emission rate) requires the following:

- Value of the height H.
- Up- and downwind vertical profiles to H of the horizontal wind vector.
- Up- and downwind vertical profiles to H of the pollutant concentration.

For individual roadways, conventional air quality sensors mounted on fixed masts are used to obtain concentration profiles. Remote sensors may be more desirable conceptually because of their path-averaging capabilities, but the state-of-the-art is generally not yet sufficiently advanced for this purpose. One possible exception is the correlation spectrometer which may have application in the evaluation of emission rates from elevated point sources. In this case (i.e., tall stack), the pollutants are emitted into an atmospheric regime where the wind shear is small. Hence, the mass flux equation may be rewritten, where

$$Q \simeq \bar{u} \left\{ \iint \chi_1(z)dydz - \iint \chi_2(z)dydz \right\} .$$

The correlation spectrometer provides the vertical mass loading; crosswind (y) traverses up- and downwind of the plume can thus be used together with the mean transport wind to determine Q (gm sec^{-1}).

In conclusion, we stress the need to evaluate the parameterization of both inputs and subsequent output emissions by models, thus ascertaining the representativeness of the parameters that are input to the inventory and evaluating the precision with which the emissions are subsequently modeled.

4. Resolution of Source Location

A major practical concern in developing an emissions inventory is the degree of resolution required in specifying the location of the point sources. Normally, point sources are resolved to 100 meters in operational inventories; however, subsequent errors introduced in predicting concentrations from such sources may be intolerable in a research study. A 10-meter resolution in source location has been proposed. Before adopting such a specification, it seems desirable to objectively evaluate errors in the predicted concentration field resulting from a mislocation of the source.

Perhaps the most difficult task in the evaluation process is the definition of a meaningful measure of the error (i.e., the difference in predictions with and without an error in the source location). We recognize that this error can be a function of many parameters: source strength, stack height, lateral and longitudinal receptor position, and atmospheric stability. For this evaluation, a worst-case meteorological situation should be used in order to determine the most stringent source-location resolution required. However, a single stability category cannot be used to satisfy this criterion as the worst-case stability for a low stack can differ from that for a tall stack. We have chosen, therefore, two stability regimes--slightly stable (Class E) and slightly unstable (Class C). Source strength and stack height will be seen to be inputs in the assessment methodology, and thus the individual source features are retained. For the impact on receptor location, two alternatives exist: (1) the user is concerned with the error associated with a particular source at one or more specified receptor location (e.g., air quality monitoring site), or (2) the user wishes to evaluate the impact of a particular source throughout the study region. Therefore, we define, as the measure of error, the integral value of the error over both the lateral (crosswind) and longitudinal (downwind) directions; the longitudinal distance may be taken as the distance either to the receptor or to the downwind edge of the study region.

The error in concentration resulting from mislocation of a source is equivalent to that which would result if a receptor were similarly mislocated. We shall take this source location error to be the absolute value of the difference between the concentration χ at the correct location and the concentration χ_E at a point some crosswind distance away. A basic Gaussian plume formulation for atmospheric dispersion is assumed

$$\chi = \frac{Q}{\pi \sigma_y \sigma_z \overline{u}} \exp\left\{-\frac{1}{2}\left[\left(\frac{y}{\sigma_y}\right)^2 + \left(\frac{H}{\sigma_z}\right)^2\right]\right\}$$

$$\chi_E = \frac{Q}{\pi \sigma_y \sigma_z \overline{u}} \exp\left\{-\frac{1}{2}\left[\left(\frac{y + \Delta y}{\sigma_y}\right)^2 + \left(\frac{H}{\sigma_z}\right)^2\right]\right\}$$

where

Q = source strength (gm $\sec^{-1}$).

Δy = source location error (m).

y = crosswind direction (m).

H = source height (m).

$\overline{u}$ = effective transport wind speed (m $\sec^{-1}$).

σ_y, σ_z = horizontal and vertical standard deviation of the pollutant distribution, respectively (m).

$\sigma_y = ax^b$.

$\sigma_z = cx^d$.

a, b, c, d = experimentally determined constants dependent on stability conditions.

x = distance along the mean wind direction from the source (m).

We define the integrated measure of error, IE, as

$$(IE) = \int_x \int_y \left| \chi - \chi_E \right| \, dydx \quad . \tag{1}$$

Since Q and $\bar{u}$ are constant over the integration, it is possible to define an integrated normalized concentration error, INE, which is independent of these quantities.

$$(IE) = \frac{Q}{\pi \bar{u}} (INE) \quad . \tag{2}$$

To determine the allowable source location error, Δy, for known values of Q, H, $\bar{u}$, stability and downwind distance, Equation (2) is solved for INE, which is then used to obtain Δy from Figures 17 through 24. However, Equation (2) contains two unknowns, IE and INE. In order to solve Equation (2), a value for IE that represents a tolerable level of concentration error must be defined as a reference. The magnitude of this reference value may be arbitrarily chosen; the error limit presented here is specified on the basis of (1) a reference source strength, $Q_{reference}$, and (2) an allowable source location error for that strength (from which $(INE)_{reference}$ is found using Figures 17 through 24). Thus, IE in Equation (2) becomes IE^*, the reference integrated error at downwind distance x for a specific source height and stability.

$$(IE)^* = \frac{Q_{reference}}{\pi \bar{u}} (INE)_{reference} \quad . \tag{3}$$

Combination of Equations (2) and (3), where IE now equals IE^*, yields an equation for INE:

$$(INE) = (INE)_{reference} \frac{Q_{reference}}{Q} \quad . \tag{4}$$

The tolerable resolution Δy is then determined (from Figures 17 through 24) on the basis of INE together with atmospheric stability, source height, and the selected downwind distance. Figures 17 through 20 apply to stable atmospheric conditions, while Figures 21 through 24 apply to unstable ones. Source heights of 0, 5, 30, and 100 meters are used in the figures, while Δy values are 5, 15, 30, 60, and 100 meters; interpolation must be used for intermediate values. A step-by-step procedural outline and example follow. Note that a minimum Δy of 10 meters is recommended because of the impact of stack diameter and initial mixing in limiting the occurrence of smaller values.

The determination comprises the following steps:

Step	Task
1.	Select stability category (stable or unstable), stack height (H), downwind distance (x), $Q_{reference}$, and Δy reference.
2.	Using stability, H, x, and Δy reference, determine $INE_{reference}$ from Figures 17 and 24.
3.	Select Q, and using it, $INE_{reference}$, and $Q_{reference}$, solve Equation (4) for INE.
4.	Using stability, H, x, and INE, determine Δy from Figures 17 through 24; let $\Delta y = 10$ meters when analysis indicates a lesser value.

For example, we shall use a reference source strength, $Q_{reference}$, of 100 tons per year, i.e., the value given by the Code of Federal Regulations to delineate between treatment of a source as a point or area source. The source location error generally accepted at the present in the most emission inventories is 100 meters, so we shall take Δy as 100 meters. For the specific case of say an 85,000 tons-per-year source strength, a stack height of 30 meters (typical of a power plant stack in Saint Louis), in stable atmospheric conditions, at a receptor point of 10 km downwind of the stack, $INE_{reference}$ is found to be 409 from the appropriate graph--Figure 19. Use of Equation (4) then gives

$$(INE) = (409)\ \frac{100 \text{ tons/year}}{85{,}000 \text{ tons/year}} = 0.48 \ .$$

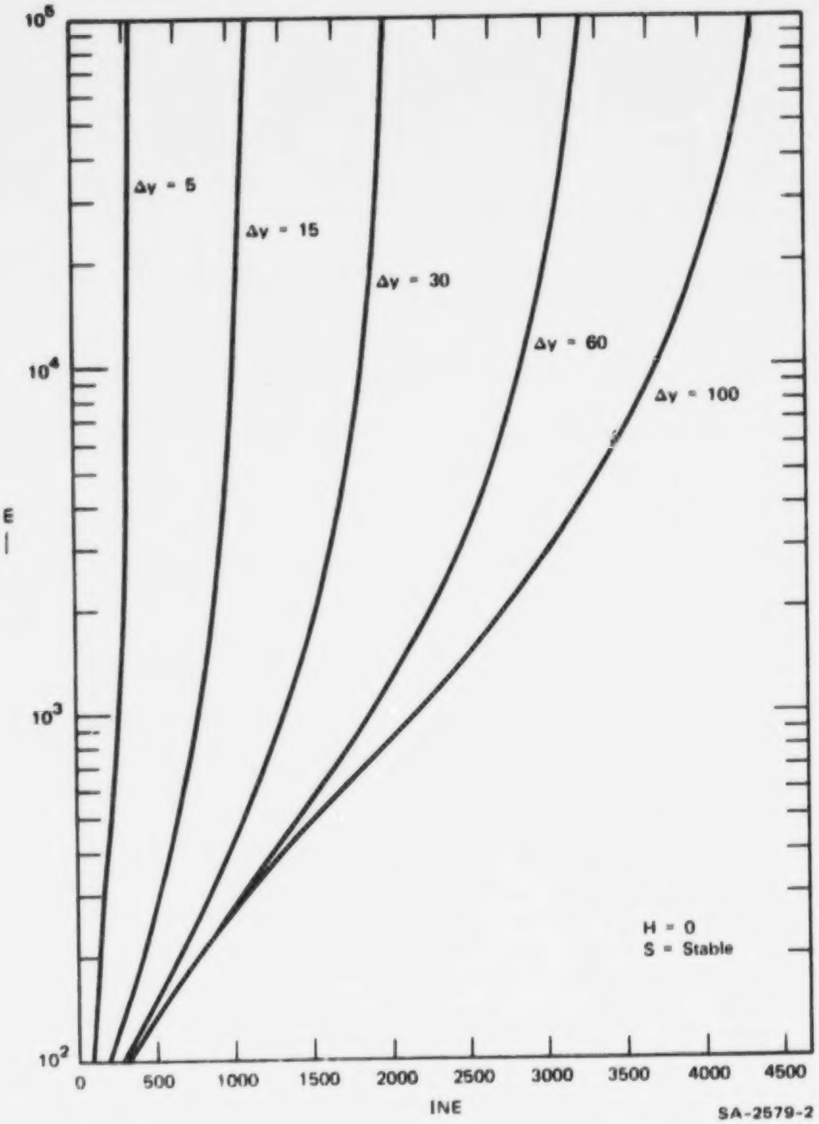

FIGURE 17 VARIATION OF INTEGRATED NORMALIZED ERROR WITH LONGITUDINAL DISTANCE FROM THE SOURCE WHEN SOURCE HEIGHT IS AT THE SURFACE AND ATMOSPHERIC CONDITIONS ARE STABLE

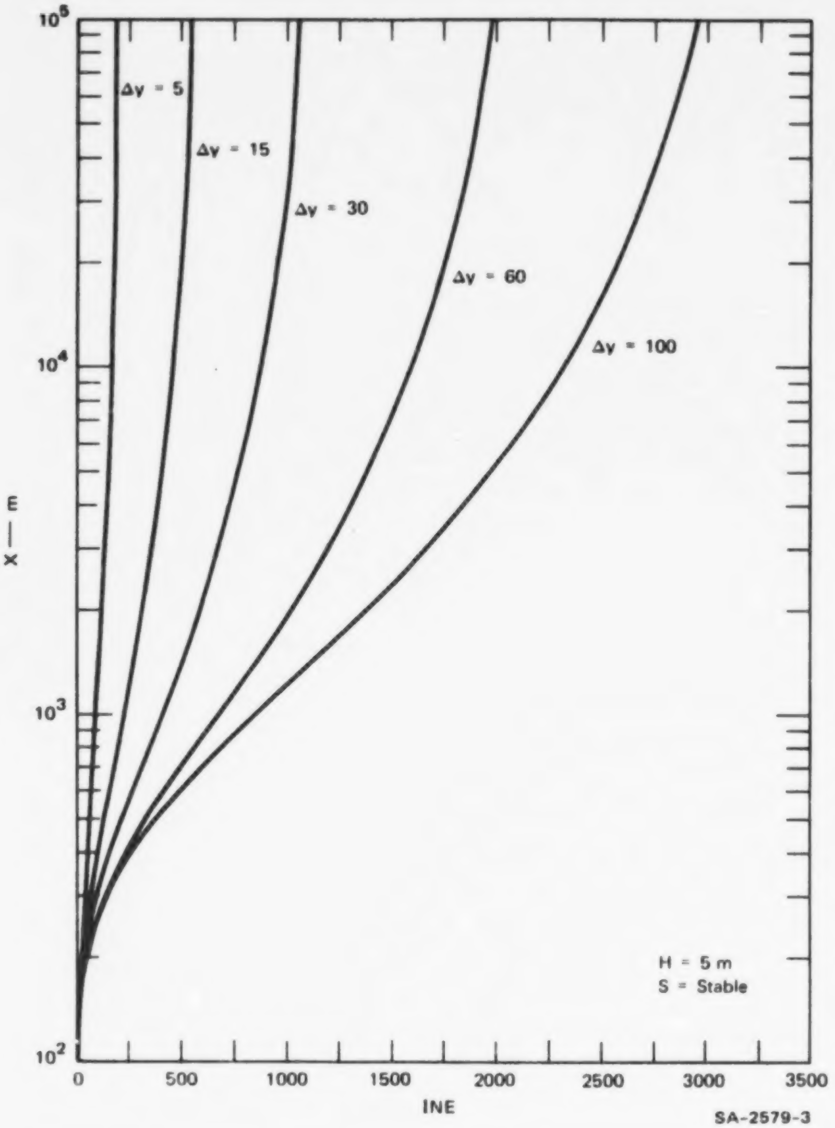

FIGURE 18 VARIATION OF INTEGRATED NORMALIZED ERROR WITH LONGITUDINAL DISTANCE FROM THE SOURCE WHEN THE SOURCE HEIGHT IS FIVE METERS AND ATMOSPHERIC CONDITIONS ARE STABLE

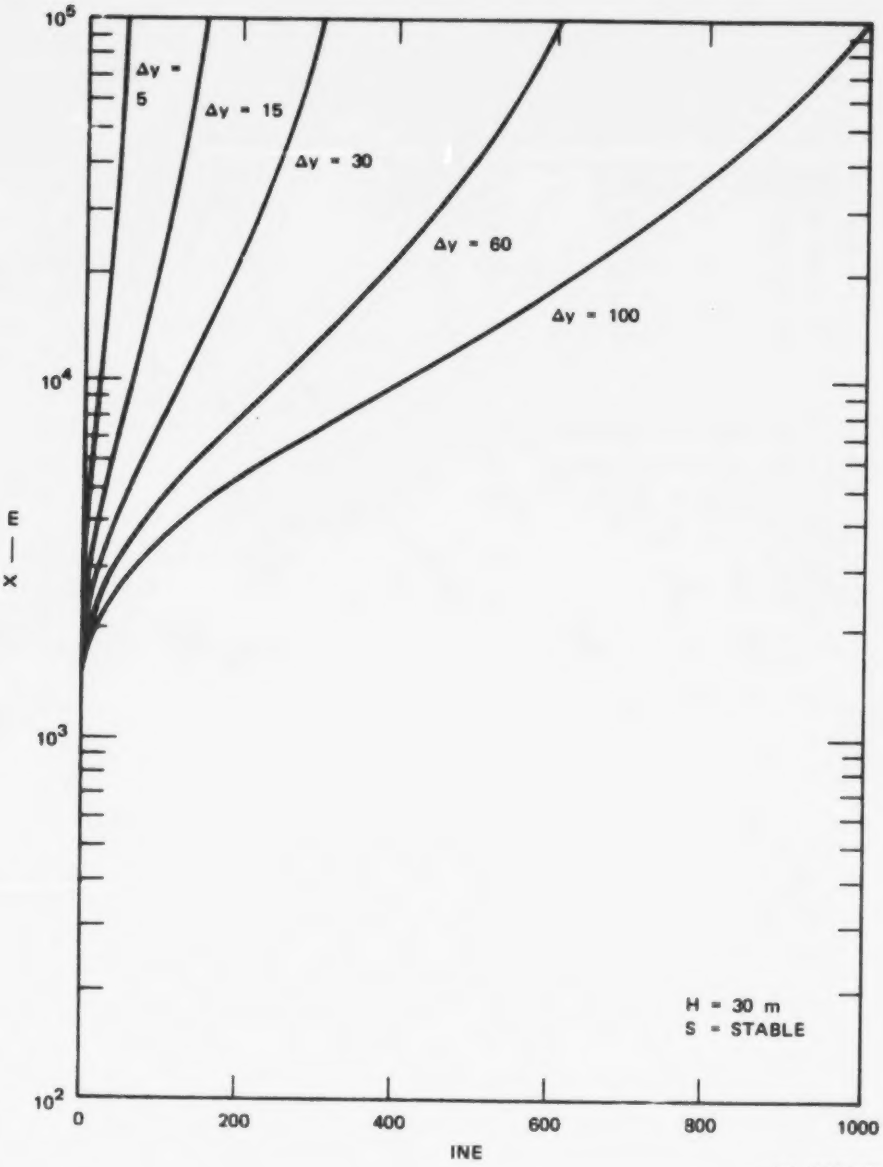

FIGURE 19 VARIATION OF INTEGRATED NORMALIZED ERROR WITH LONGITUDINAL DISTANCE FROM THE SOURCE WHEN SOURCE HEIGHT IS 30 METERS AND ATMOSPHERIC CONDITIONS ARE STABLE

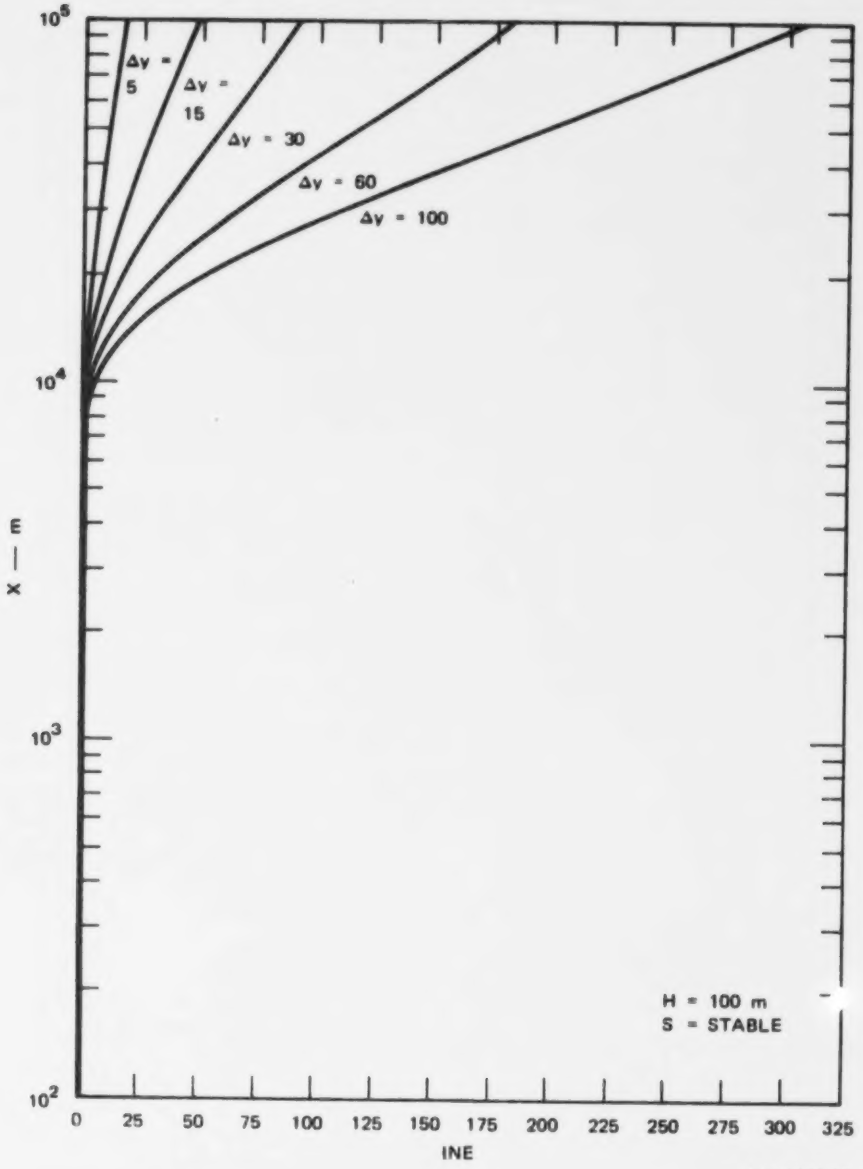

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FIGURE 20 VARIATION OF INTEGRATED NORMALIZED ERROR WITH LONGITUDINAL DISTANCE FROM THE SOURCE WHEN SOURCE HEIGHT IS 100 METERS AND ATMOSPHERIC CONDITIONS ARE STABLE

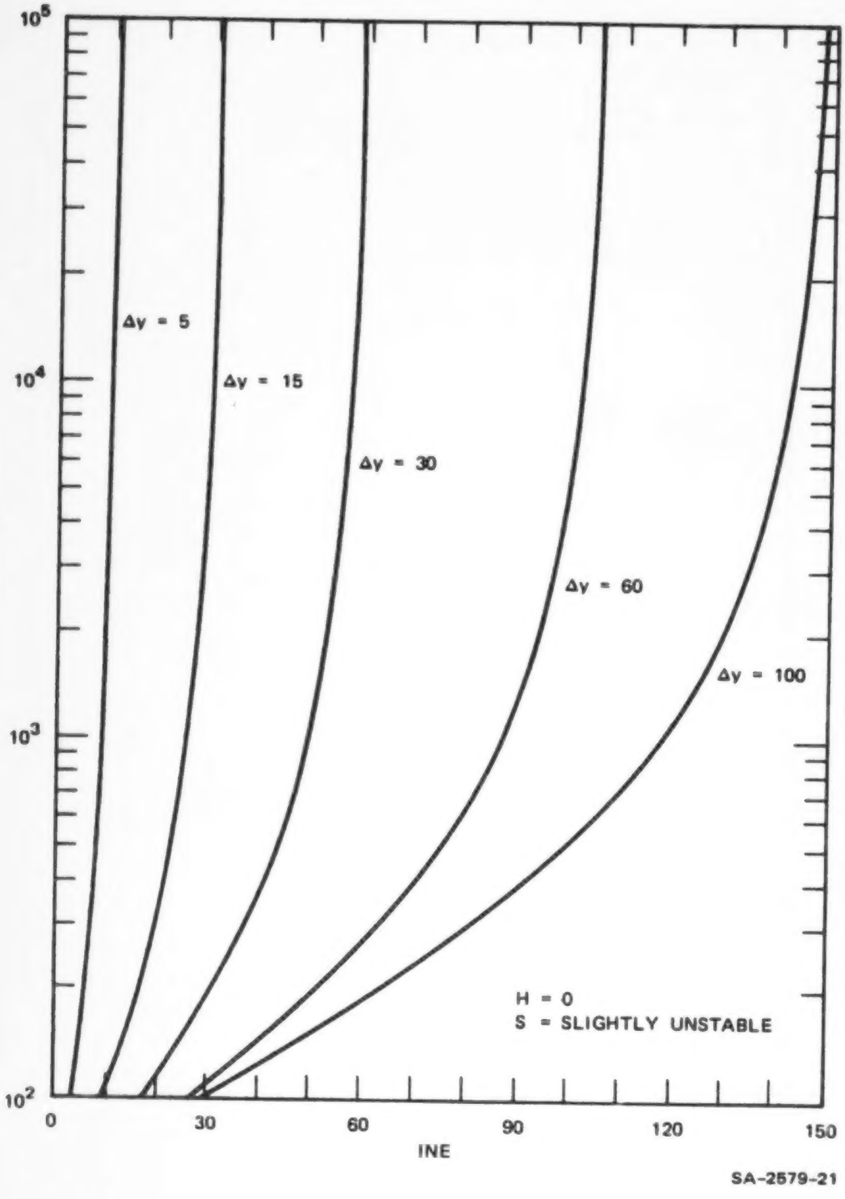

FIGURE 21 VARIATION OF INTEGRATED NORMALIZED ERROR WITH LONGITUDINAL DISTANCE FROM THE SOURCE WHEN THE SOURCE HEIGHT IS AT THE SURFACE AND ATMOSPHERIC CONDITIONS ARE SLIGHTLY UNSTABLE

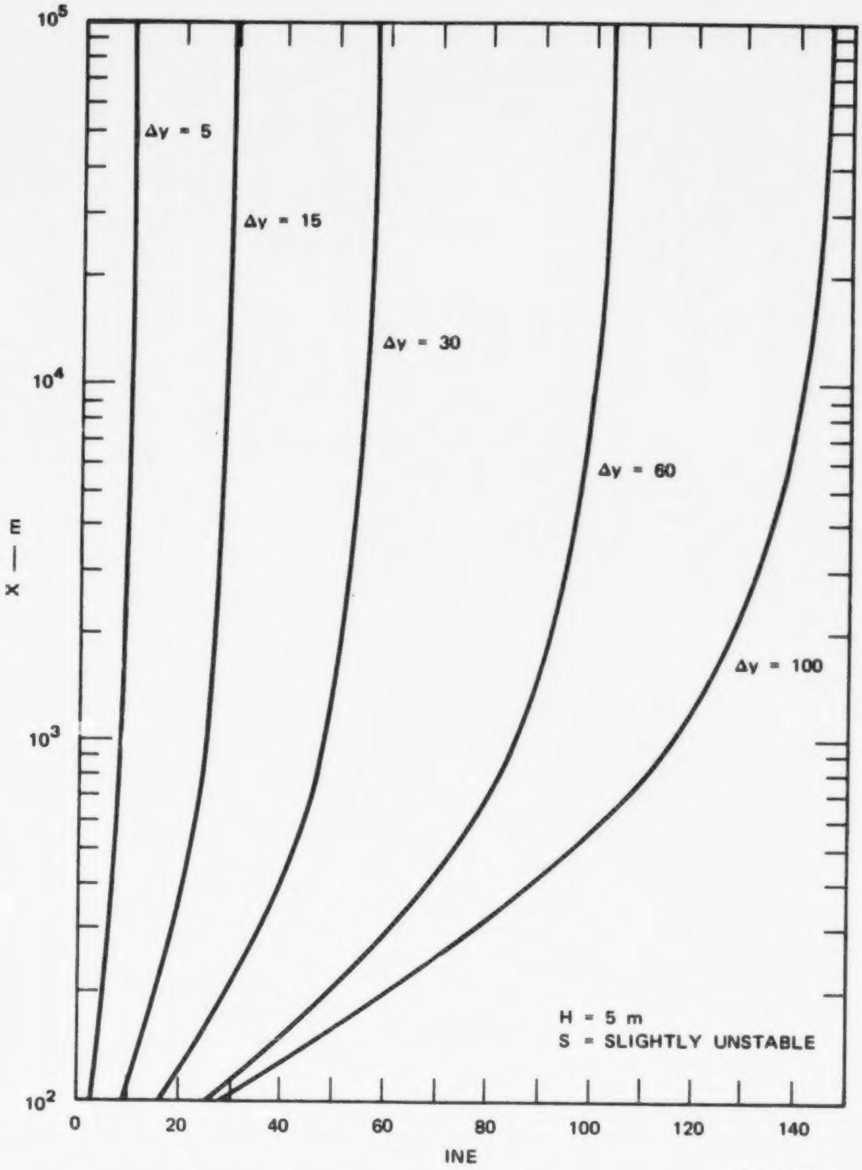

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FIGURE 22 VARIATION OF INTEGRATED NORMALIZED ERROR WITH LONGITUDINAL DISTANCE FROM THE SOURCE WHEN SOURCE HEIGHT IS FIVE METERS AND ATMOSPHERIC CONDITIONS ARE SLIGHTLY UNSTABLE

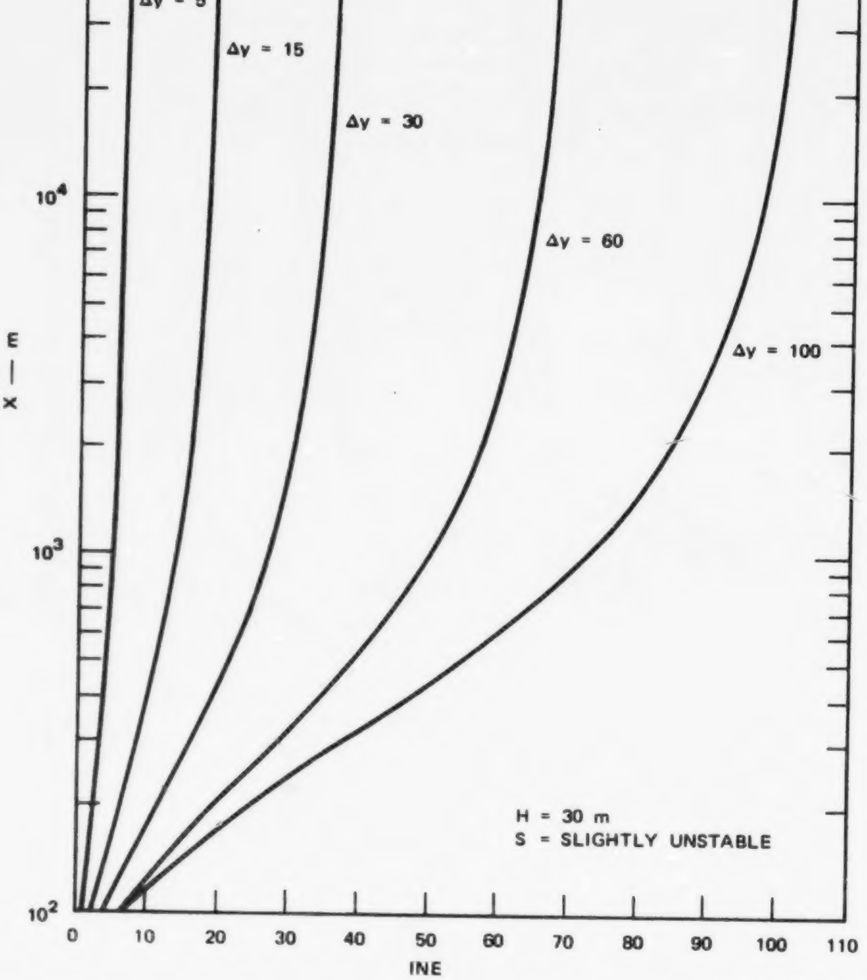

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FIGURE 23 VARIATION OF INTEGRATED NORMALIZED ERROR WITH LONGITUDINAL DISTANCE FROM THE SOURCE WHEN SOURCE HEIGHT IS 30 METERS AND ATMOSPHERIC CONDITIONS ARE SLIGHTLY UNSTABLE

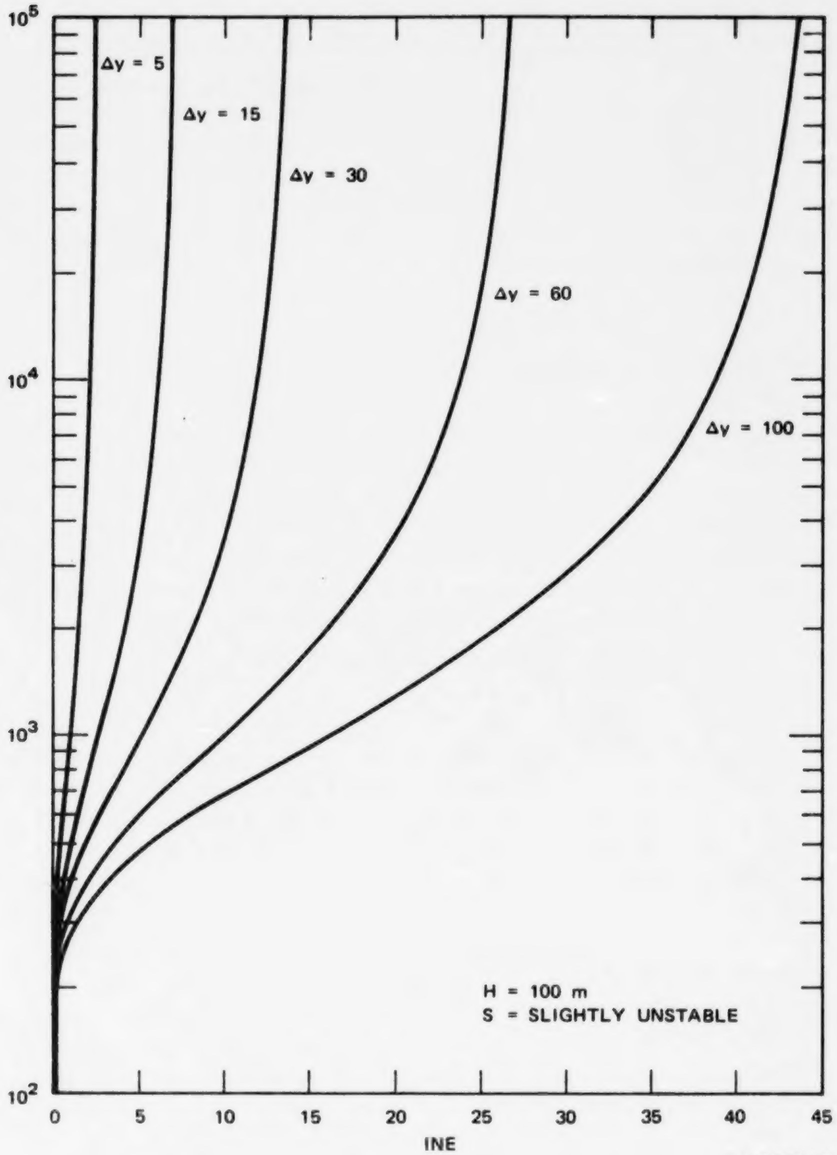

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FIGURE 24 VARIATION OF INTEGRATED NORMALIZED ERROR WITH LONGITUDINAL DISTANCE FROM THE SOURCE WHEN SOURCE HEIGHT IS 100 METERS AND ATMOSPHERIC CONDITIONS ARE SLIGHTLY UNSTABLE

The resulting Δy for this INE, obtained from Figure 19, is very small, suggesting that such a large source must be precisely located, i.e., within 10 meters. With a source strength of 1,000 tons per year and other variables as above, Δy is approximately 18 meters.

A significant feature of this method is its flexibility: The error measure can be taken to most any selected downwind distance or distance interval. In addition, rather than specifying a single resolution required of all stacks, the method yields a recommended spatial resolution for each source based on the stack height and emission rate of the individual source.

C. Consideration of Natural Emissions

Pollutant emissions from natural phenomena require evaluation in the development of an accurate inventory for the region. The natural emissions or production of CO, NO, NO_2, SO_2, nonmethane hydrocarbons, and particulate material in the Saint Louis area are generally small compared with other pollution emissions, but some are large enough to produce a measurable background. There is enough known about the production of the primary pollutants in the biosphere or atmosphere to estimate the production rates or source strengths within a selected area and volume.

For the purposes of RAPS, the Saint Louis source area can be defined as a circle of 35 kilometers radius centered in the business district of Saint Louis. Urban and suburban areas include East Saint Louis, Granite City, Alton, and Belleville (all in Illinois). The area of this circle is about 4000 km^2, the estimated vegetated source area is half of this, or 2000 km^2.

The source strengths of each of the five emission components will be estimated according to its potential production mechanism or mechanisms active in this particular area. Calculated atmospheric concentrations in the Saint Louis area resulting from these emissions must also include background concentrations of the air transported into the Saint Louis air space if a realistic value is to be obtained.

Carbon monoxide is produced naturally in the atmosphere by the oxidation of methane.[31] Atmospheric methane is largely naturally produced from decay of vegetation. The best estimated global production rate is about $2x10^9$ tons per year. All of this methane is oxidized in the atmosphere to produce more than $3x10^9$ tons of CO annually. The CO, in turn, is oxidized to CO_2. The 4000 km^2 area chosen is $8x10^{-6}$ of the global area; therefore, the average daily CO production rate is estimated at 70 tons per day.

There are no known natural sources of NO_2 but, NO is generated by vegetation.[32] The global NO natural production rate is 500 x 10^6 tons per year, from an approximate $1x10^8$ km^2 vegetation covered area. If we use the 2000 km^2 area for trees and shrubery, NO production in the region is about 30 tons per day.

All of the SO_2 produced naturally in the area would result from ozone oxidation of H_2S, again generated by the decay of vegetation. The total annual production of H_2S from the $1x10^8$ km^2 of land areas of the earth is about $70x10^6$ tons.[33] Using the same area ratio as for NO gives an estimated production of 4 tons of H_2S per day. If we consider the 4 tons H_2S to be oxidized in situ, it produces 8 tons of SO_2 per day.

The nonmethane hydrocarbons emitted naturally are all terpenes or isoprene. Pipperton estimates worldwide natural emissions of these substances to be 10^9 tons per year.[34] Hence, 50 tons per day of nonmethane hydrocarbons are produced in the area. The diurnal variation in terpene vapor emission rates is extreme; nearly all of these vapors are released from plants during the hours of daylight. There is also a seasonal variation with a summer maximum and a winter minimum. All of the vapors are released through the foliage. Through the year, the hourly rate of emission will vary from essentially zero (winter night) to about 10 tons per hour (summer daylight maximum).

Natural particulates in the atmosphere of the Saint Louis region are mostly the product of chemical reaction. The oxidation of SO_2 to sulfate and NO_x to nitrate and the formation of polymeric organic particles from terpenes produce most of the background. The only direct natural particulate in the Saint Louis area is dust. The dust loading will vary widely with wind speed. The average dust loading is 5 $\mu g/m^3$. The secondary or condensed aerosol from natural sources adds about 15 to 20 $\mu g/m^3$ to the background.

The yearly global average for dust generated, 200 x 10^6 tons,[33] is reasonable to apply to the Saint Louis area; thus, the average dust production in the Saint Louis region is about 25 tons per day.

Table 27 summarizes the estimated emissions of CO, NO_x, SO_2, H_2S, nonmethane HC, and particulates from natural sources alone and all sources in the Saint Louis region. Carbon monoxide, SO_2 and NO_x production from natural sources is only a small part of the total regional production and can be expected to have little impact on the RAPS studies.

Particulates from natural sources are of marginal significance. Nonmethane HC, on the other hand, may be significant during summer daylight periods. Therefore, we recommend that a procedure be developed for estimating the contribution of natural HC for incorporation in the RAPS Emission Inventory.

Table 27

POLLUTANT EMISSIONS IN THE
SAINT LOUIS AREA*
(Tons/Day)

Type	Natural	Total
CO	70	5100
NO_x	30†	810
SO_x	0	2040
H_2S	4	--
Nonmethane hydrocarbons	50‡	790
Particulate (dust)	25	520

*The area is 4000 km^2 in size.

†Expressed as NO.

‡Maximum rate = 10 tons/hour.

D. Summary of Conclusions and Recommendations

The specific conclusions and recommendations that result from the studies carried out under this task are summarized below:

No existing models adequately meet the requirements of RAPS; to provide emissions data with the necessary high resolution in space and time, it is recommended that

- Direct information be acquired of emissions or of factors determining emissions to the extent possible.
- Where not possible (i.e., for small point sources, and area sources), the most suitable of the existing models should be used in adapted and improved form. Specifically, for stationary sources,

- Direct data from emissions monitoring should be used wherever available (probably only for the largest sources, such as power stations).
- For other large sources, information on hourly fuel consumption rates, process operations, and such, should be obtained and used to derive emissions.
- For small point sources and area sources, modeling procedures based upon the models noted below (but, with refinement of the input data wherever possible) should be used.

Recommended models are

- The Argonne model[2] for hourly SO_2 from distributed residential, commercial, and institutional sources and hourly SO_2 and heat from major point sources.

The Systems Applications, Inc. (SAI) model[1,3] for hourly NO_x and HC from stationary point and area sources.

For automotive mobile sources, we recommend that an average route speed model be used (with a link or line source geometry) supplemented with measured data of traffic flow from fixed sensors on high volume freeways and on selected arterials. The following models are recommended:

- The SAI model[1,3] for hourly CO, NO_x and HC with modified inputs derived from Stanford Research Institute's model[4] for spatial and temporal distribution of vehicle number and speed on a link basis for primary traffic and area basis for secondary traffic.
- Recommended for other mobile sources, are the Geomet model[5] for diurnal emissions from river vessles and railroads and the Northern Research and Engineering model,[6] as revised by Geomet (in preparation), for aircraft emissions.
- For both stationary and mobile sources, the Ontario Department of the Environment (1971) model for Toronto should be referred to for overall guidance and planning methodology.

For microscale studies under the RAPS program the basic inventory will need to be supplemented with special emission inputs. These should be obtained on an experimental or project basis. Detailed data can be acquired from small stationary sources or, for mobile sources, from continuous and detailed monitoring of vehicle behavior in a given area with the application of a multimodal emission model to forecast emissions.

In view of the limitations of existing mobile emission source models and the impossibility of resorting to direct information (as is done in the case with major stationary sources), it is recommended that special steps be taken to improve and verify such mobile emission models. Specifically,

- An experimental evaluation should be made of mobile emissions models to refine the specification of process input parameters and the accuracy of postulated input-output relationships.
- Parameterization of inputs for mobile emissions (statistical database plus continuous measurements of vehicle volume, speed, and mix on key links to generate a dynamic link-by-link inventory) should be verified on a selective basis via aerial photography or side-looking aerial radar or both.
- Temporal and spatial variations of fuel consumption by distributed area sources should be spot metered in fine scale.
- Parameterization of outputs from mobile sources should be evaluated in various models to verify representation of time-averaged emissions on a per-link basis taking into account types of link and the impacts of deterioration, mix, road grade, drag, and so forth.
- Of the pollutant emissions (CO, NO_x, SO_2, H_2S, nonmethane HC, and particulates) from natural phenomena in the Saint Louis area, nonmethane HC may contribute a significant background during summer daylight hours and should be included in the RAPS emission inventory. Suitable procedures to estimate these should be developed early in the RAPS program.
- In the context of the RAPS program, the accuracy of point source locations is best considered in terms of the effect of errors throughout the study area. Accordingly, we propose that a measure of error in source location be defined as the integral value of the error over both the lateral (cross wind) and longitudinal (downwind) directions.

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Appendix A

SAMPLE EMISSION INVENTORY PRINTOUTS

This appendix consists of 12 figures listed on the following page.

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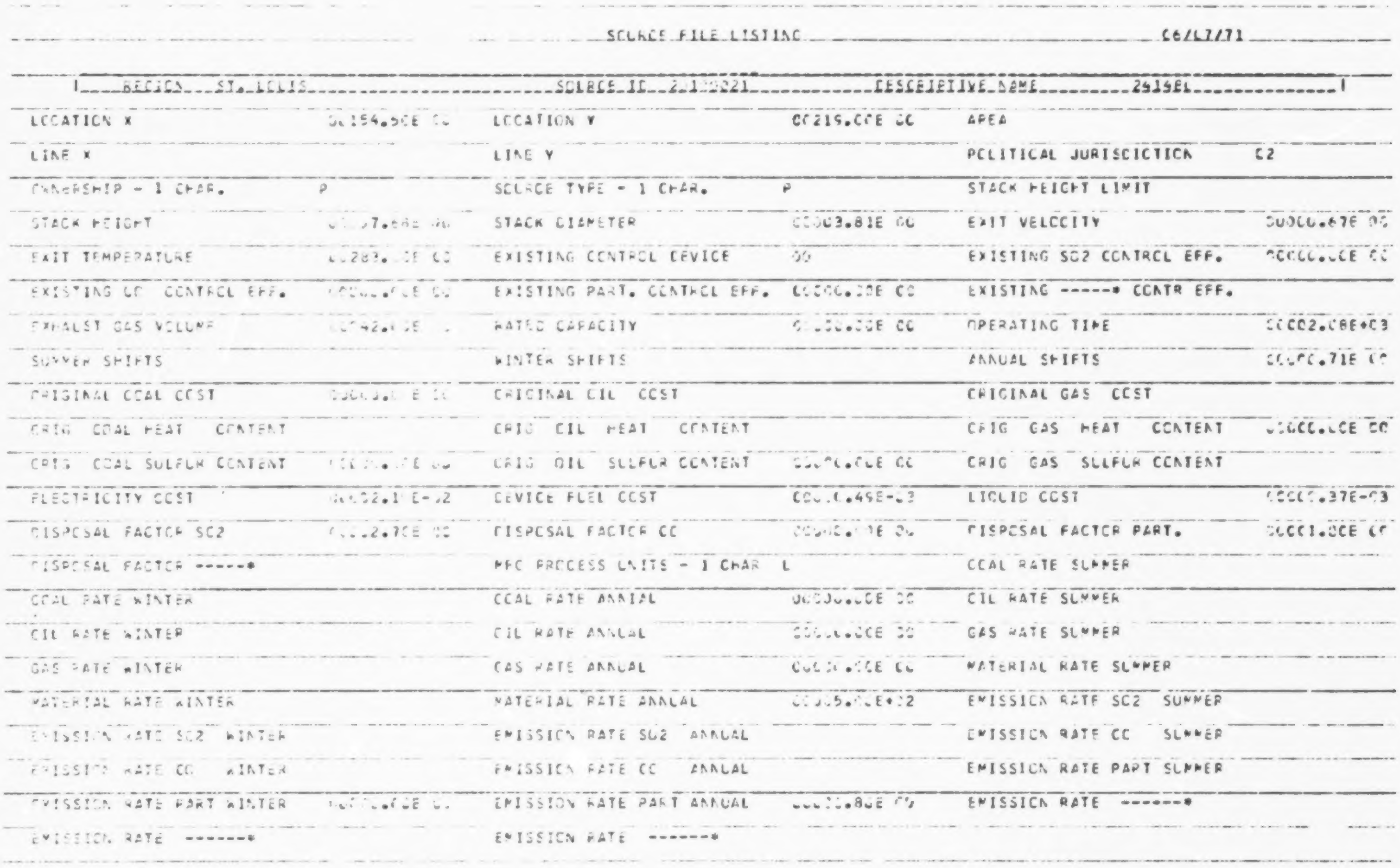

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                                        SOURCE FILE LISTING                                        06/17/71

  I    REGION   ST. LOUIS                     SOURCE ID  2310021               DESCRIPTIVE NAME        2419EL               I

LOCATION X                   00154.50E 00   LOCATION Y                    00219.00E 00   AREA

LINE X                                      LINE Y                                       POLITICAL JURISDICTION      02

OWNERSHIP - 1 CHAR.       P                 SOURCE TYPE - 1 CHAR.       P                STACK HEIGHT LIMIT

STACK HEIGHT                 00007.68E 00   STACK DIAMETER                00003.81E 00   EXIT VELOCITY                 00000.67E 02

EXIT TEMPERATURE             00283.00E 00   EXISTING CONTROL DEVICE       00             EXISTING SO2 CONTROL EFF.     00000.00E 00

EXISTING CO  CONTROL EFF.    00000.00E 00   EXISTING PART. CONTROL EFF.   00000.00E 00   EXISTING -----* CONTR EFF.

EXHAUST GAS VOLUME           00042.00E 00   RATED CAPACITY                00000.00E 00   OPERATING TIME                00002.08E+03

SUMMER SHIFTS                               WINTER SHIFTS                                ANNUAL SHIFTS                 00000.71E 00

ORIGINAL COAL COST           00000.00E 00   ORIGINAL OIL  COST                           ORIGINAL GAS  COST

ORIG  COAL HEAT   CONTENT                   ORIG  OIL  HEAT   CONTENT                    ORIG  GAS  HEAT   CONTENT     00000.00E 00

ORIG  COAL SULFUR CONTENT    00000.00E 00   ORIG  OIL  SULFUR CONTENT     00000.00E 00   ORIG  GAS  SULFUR CONTENT

ELECTRICITY COST             00002.10E-02   DEVICE FUEL COST              00000.49E-03   LIQUID COST                   00000.37E-03

DISPOSAL FACTOR SO2          00002.70E 00   DISPOSAL FACTOR CO            00000.00E 00   DISPOSAL FACTOR PART.         00001.00E 00

DISPOSAL FACTOR -----*                      MPC PROCESS UNITS - 1 CHAR  L                COAL RATE SUMMER

COAL RATE WINTER                            COAL RATE ANNUAL              00000.00E 00   OIL RATE SUMMER

OIL RATE WINTER                             OIL RATE ANNUAL               00000.00E 00   GAS RATE SUMMER

GAS RATE WINTER                             GAS RATE ANNUAL               00000.00E 00   MATERIAL RATE SUMMER

MATERIAL RATE WINTER                        MATERIAL RATE ANNUAL          00005.00E+02   EMISSION RATE SO2  SUMMER

EMISSION RATE SO2  WINTER                   EMISSION RATE SO2  ANNUAL                    EMISSION RATE CO   SUMMER

EMISSION RATE CO   WINTER                   EMISSION RATE CO   ANNUAL                    EMISSION RATE PART SUMMER

EMISSION RATE PART WINTER    00000.00E 00   EMISSION RATE PART ANNUAL     00000.80E 00   EMISSION RATE  ------*

EMISSION RATE  ------*                      EMISSION RATE  ------*
```

FIGURE A-1 TYPICAL SOURCE PRINTOUT FROM IPP INVENTORY

```
                                    SOURCE FILE LISTING                                             06/27/71

   I    REGION   ST. LOUIS                        SOURCE ID  5555.612              DESCRIPTIVE NAME                                 I

LOCATION X                  00149.40E 03   LOCATION Y                    00231.60E 00   AREA                              00009.29E 00
LINE X                                     LINE Y                                       POLITICAL JURISDICTION      03
OWNERSHIP - 1 CHAR.                        SOURCE TYPE - 1 CHAR.                        STACK HEIGHT LIMIT
STACK HEIGHT                00010.00E 00   STACK DIAMETER                               EXIT VELOCITY
EXIT TEMPERATURE                           EXISTING CONTROL DEVICE                      EXISTING SO2 CONTROL EFF.
EXISTING CO  CONTROL EFF.                  EXISTING PART. CONTROL EFF.                  EXISTING -----* CONTR EFF.
EXHAUST GAS VOLUME                         RATED CAPACITY                               OPERATING TIME
SUMMER SHIFTS                              WINTER SHIFTS                                ANNUAL SHIFTS
ORIGINAL COAL COST                         ORIGINAL OIL  COST                           ORIGINAL GAS  COST
ORIG  COAL HEAT   CONTENT                  ORIG  OIL  HEAT   CONTENT                    ORIG  GAS  HEAT   CONTENT
ORIG  COAL SULFUR CONTENT                  ORIG  OIL  SULFUR CONTENT                    ORIG  GAS  SULFUR CONTENT
ELECTRICITY COST                           DEVICE FUEL COST                             LIQUID COST
DISPOSAL FACTOR SO2                        DISPOSAL FACTOR CO                           DISPOSAL FACTOR PART.
DISPOSAL FACTOR -----*                     MFG PROCESS UNITS - 1 CHAR                   COAL RATE SUMMER
COAL RATE WINTER                           COAL RATE ANNUAL                             OIL RATE SUMMER
OIL RATE WINTER                            OIL RATE ANNUAL                              GAS RATE SUMMER
GAS RATE WINTER                            GAS RATE ANNUAL                              MATERIAL RATE SUMMER
MATERIAL RATE WINTER                       MATERIAL RATE ANNUAL                         EMISSION RATE SO2  SUMMER
EMISSION RATE SO2  WINTER                  EMISSION RATE SO2  ANNUAL     00008.50E-02   EMISSION RATE CO   SUMMER
EMISSION RATE CO   WINTER                  EMISSION RATE CO   ANNUAL                    EMISSION RATE PART SUMMER
EMISSION RATE PART WINTER                  EMISSION RATE PART ANNUAL     00001.90E-01   EMISSION RATE  ------*
EMISSION RATE  ------*                     EMISSION RATE  ------*
```

FIGURE A-2   TYPICAL AREA SOURCE PRINTOUT FROM IPP INVENTORY

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SOURCE NUMBER	REGION	STANDARD INDUSTRIAL CLASS.	SITE	PROCESS CODE	SOURCE IDENTIFICATION	X COORDINATE KM	Y COORDINATE KM	POLITICAL JURISDICTION	OWNER	TYPE	OPER. HOURS
51	070	3565		1	STANDARD ARMAMENT	474.	736.	11	PRIVATE	PROCESS	[illegible]
52	070	2992		1	J.D. STREET	477.	712.	11	PRIVATE	PROCESS	8760
53	070	2992		1	TEXACO	464.	657.	11	PRIVATE	PROCESS	8760
54	070	2992		1	UNION CARBIDE CO	476.	[illegible]	11	PRIVATE	PROCESS	[illegible]
55	070	4911		10	UNION ELECTRIC MOUND ST	[illegible]	719.0	11	UTILITIES	BOILER	[illegible]
56	070	3569		1	VITRO PRODUCTS	452.	724.	11	PRIVATE	PROCESS	[illegible]
57	070	3241	002	2	ALPHA PORTLAND CEMENT	454.2	678.0	12	PRIVATE	PROCESS	8760
58	070	3295	001	1	HUSSEN QUARRY	410.6	755.7	12	PRIVATE	PROCESS	[illegible]
59	070	2555		1	CONTINENTAL CAN CO	451.0	777.4	12	PRIVATE	PROCESS	
60	070	3639		0	EMERSON ELECTRIC	406.7	751.1	12	PRIVATE	BOILER	8760
61	070	9902	002	0	HOWARD BEND PUMP STA	393.6	731.4	12	LOCAL	BOILER	8760
62	070	9902	003	0	JEFFERSON BARRACKS HOSP	467.4	663.5	12	FEDERAL	BOILER	8760
63	070	3411		1	LIANCO CONTAINER CORP	[illegible]	764.[illegible]	12	PRIVATE	PROCESS	[illegible]
64	070	3241	001	2	MISSOURI PORTLAND CEMNT	405.4	752.[illegible]	12	PRIVATE	PROCESS	8760
65	070	2851		3	NATIONAL LEAD TITANIUM	472.3	679.0	12	PRIVATE	BOILER	8760
66	070	2851		0	NATIONAL LEAD TITANIUM	472.3	677.[illegible]	12	PRIVATE	BOILER	8760
67	070	2899	001	1	NATIONAL LEAD TITANIUM	472.3	679.0	12	PRIVATE	PROCESS	8760
68	070	2897	002	1	NATIONAL LEAD TITANIUM	472.3	679.0	12	PRIVATE	PROCESS	8760
69	070	4953		1	ST. LOUIS MSD LEMAY	465.0	674.[illegible]	12	LOCAL	SOLID WASTE	[illegible]
70	070	4911	001	0	UNION ELEC MERAMEC 162	452.6	631.7	12	UTILITIES	BOILER	[illegible]
71	070	911	001	0	UNION ELEC. MERAMEC 145	[illegible]	3172.0	12	UTILITIES	BOILER	[illegible]
72	070	4911	002	0	UNION ELEC MERAMEC 364	452.0	631.7	12	UTILITIES	BOILER	[illegible]
73	070	4911	002	0	UNION ELEC MERAMEC 364	457.0	631.7	12	UTILITIES	BOILER	[illegible]
74	070	3295	002	1	WIGGS QUARRY	415.3	665.5	12	PRIVATE	PROCESS	[illegible]
75	070	2752		1	WESTERN LITHO PLATE	418.2	688.8	12	PRIVATE	PROCESS	[illegible]
76	070	9902	001	0	WASHINGTON UNIVERSITY	[illegible]	740.0	12	PRIVATE	BOILER	8760
77	070	2899		0	TRETOLITE DIV PETROLITE	[illegible]	213.[illegible]	12	PRIVATE	BOILER	[illegible]
78	070	3999		0	MCDONNELL DOUGLAS CORP	135.0	232.0	12	PRIVATE	BOILER	8760
79	070	3999	001	1	MCDONNELL DOUGLAS CORP	135.0	232.0	12	PRIVATE	PROCESS	[illegible]
80	070	3999	002	1	MCDONNELL DOUGLAS CORP	135.0	[illegible]	12	PRIVATE	PROCESS	4160
81	070	3999	003	1	MCDONNELL DOUGLAS CORP	135.0	232.0	12	PRIVATE	PROCESS	4160
82	070	3999	004	1	MCDONNELL DOUGLAS CORP	135.0	232.0	12	PRIVATE	PROCESS	4160
83	070	3999	005	1	MCDONNELL DOUGLAS CORP	135.0	232.0	12	PRIVATE	PROCESS	4160
84	070	3999	006	1	MCDONNELL DOUGLAS CORP	135.0	232.0	12	PRIVATE	PROCESS	4160
85	070	3999	007	1	MCDONNELL DOUGLAS CORP	135.0	232.0	12	PRIVATE	PROCESS	4160
86	070	3999	008	1	MCDONNELL DOUGLAS CORP	135.0	232.0	12	PRIVATE	PROCESS	[illegible]
87	070	3999	009	1	MCDONNELL DOUGLAS CORPM	135.0	232.0	12	PRIVATE	PROCESS	4160
88	070	3711	002	0	FORD MOTOR CO (BOILER)	135.0	233.0	12	PRIVATE	BOILER	[illegible]
89	070	3711	001	1	FORD MOTOR CO	13.5	0 23.3	1	LOCAL	PROCESS	[illegible]
90	070	3711	002	1	FORD MOTOR CO	13.5	0 23.3	1	LOCAL	PROCESS	1365
91	070	3711	003	1	FORD MOTOR CO	13.5	0 23.3	1	LOCAL	PROCESS	[illegible]
92	070	3711	004	1	FORD MOTOR CO	13.5	0 23.3	1	LOCAL	PROCESS	[illegible]
93	070	3711	005	1	FORD MOTOR CO	13.5	0 23.3	1	LOCAL	PROCESS	[illegible]
94	070	3711	006	1	FORD MOTOR CO	13.5	0 23.3	1	LOCAL	PROCESS	[illegible]
95	070	3711	007	1	FORD MOTOR CO	13.5	0 23.3	1	LOCAL	PROCESS	1365

FIGURE A-3 · TYPICAL POINT SOURCE PRINTOUT FROM IBM INVENTORY

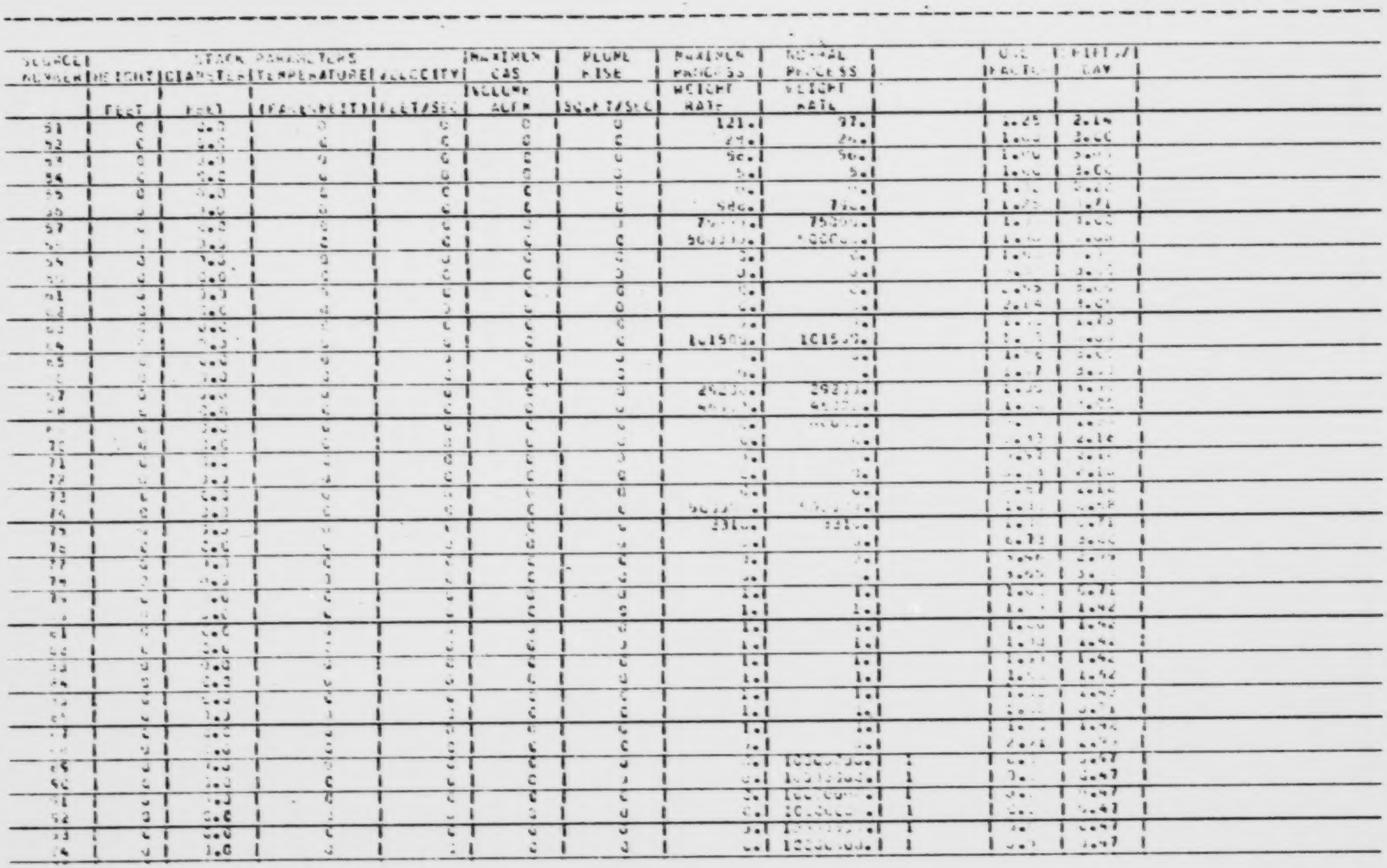

FIGURE A-3 TYPICAL POINT SOURCE PRINTOUT FROM IBM INVENTORY (continued)

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```
SOURCE| BOILER  |EMIS|   COAL    |EMIS|RESIDUAL|EMIS|DISTILLATE|EMIS|NATURAL|               HEAT CONTENT             |% ASH|       SULFUR CONTENT %        |
NUMBER|CAPACITY |FACT|           |FACT|  OIL   |FACT|   OIL    |FACT|  GAS  | COAL |RESID  |DISTIL |NAT GA | COAL | COAL |RESID|DIST.|N. GAS|
      |MMBTU/HR |    | TONS/YR.  |    |M GAL/YR|    | M GAL/YR |    |MMCF/YR|MMB/T |M B/GAL|M B/GAL|BTU/CF |      |      |     |     |      |
  51  |      0. |  0 |        0. |  0 |     0. |  0 |       0. |  0 |    0. |  0.0 |   0.0 |   0.0 |    0. |  0.0 |  0.0 | 0.0 | 0.0 | 0.0  |
  52  |      0. |  0 |        0. |  0 |     0. |  0 |       0. |  0 |    0. |  0.0 |   0.0 |   0.0 |    0. |  0.0 |  0.0 | 0.0 | 0.0 | 0.0  |
  53  |      0. |  0 |        0. |  0 |     0. |  0 |       0. |  0 |    0. |  0.0 |   0.0 |   0.0 |    0. |  0.0 |  0.0 | 0.0 | 0.0 | 0.0  |
  54  |      0. |  0 |        0. |  0 |     0. |  0 |       0. |  0 |    0. |  0.0 |   0.0 |   0.0 |    0. |  0.0 |  0.0 | 0.0 | 0.0 | 0.0  |
  55  |      9. |  0 |        0. |  0 |    29. |  0 |       0. |  0 |    0. |  0.0 | 143.0 |   0.0 |    0. |  0.0 |  0.0 | 0.0 | 0.0 | 0.0  |
  56  |      0. |  0 |        0. |  0 |     0. |  0 |       0. |  0 |    0. |  0.0 |   0.0 |   0.0 |    0. |  0.0 |  0.0 | 0.0 | 0.0 | 0.0  |
  57  |      0. |  0 |        0. |  0 |     0. |  0 |       0. |  0 |    0. |  0.0 |   0.0 |   0.0 |    0. |  0.0 |  0.0 | 0.0 | 0.0 | 0.0  |
  58  |      0. |  0 |        0. |  0 |     0. |  0 |       0. |  0 |    0. |  0.0 |   0.0 |   0.0 |    0. |  0.0 |  0.0 | 0.0 | 0.0 | 0.0  |
  59  |      0. |  0 |        0. |  0 |     0. |  0 |       0. |  0 |    0. |  0.0 |   0.0 |   0.0 |    0. |  0.0 |  0.0 | 0.0 | 0.0 | 0.0  |
  60  |      0. |  0 |     3385. |  0 |     0. |  0 |       0. |  0 |  222. | 22.7 |   0.0 |   0.0 | 1000. |  0.0 | 3.36 | 0.0 | 0.0 | 0.0  |
  61  |    218. |  0 |    33700. |  0 |     0. |  0 |       0. |  0 |    0. | 22.0 |   0.0 |   0.0 |    0. |  0.0 | 3.00 | 0.0 | 0.0 | 0.0  |
  62  |    114. |  0 |    16000. |  0 |     0. |  0 |       0. |  0 |    0. | 22.0 |   0.0 |   0.0 |    0. |  0.0 |  3.5 | 0.0 | 0.0 | 0.0  |
  63  |      0. |  0 |        0. |  0 |     0. |  0 |       0. |  0 |    0. |  0.0 |   0.0 |   0.0 |    0. |  0.0 |  0.0 | 0.0 | 0.0 | 0.0  |
  64  |      0. |  0 |        0. |  0 |     0. |  0 |       0. |  0 |    0. |  0.0 |   0.0 |   0.0 |    0. |  0.0 |  0.0 | 0.0 | 0.0 | 0.0  |
  65  |    774. |  0 |   125200. |  0 |   617. |  0 |       0. |  0 | 1366. | 22.7 | 150.0 |   0.0 | 1000. |  0.0 | 3.37 | 2.53| 0.0 | 0.0  |
  66  |    774. |  0 |    34774. |  0 |  3084. |  0 |       0. |  0 | 1373. | 21.0 | 152.0 |   0.0 | 1050. |  9.0 | 3.33 | 0.70| 0.0 | 0.0  |
  67  |      0. |  0 |        0. |  0 |     0. |  0 |       0. |  0 |    0. |  0.0 |   0.0 |   0.0 |    0. |  0.0 |  0.0 | 0.0 | 0.0 | 0.0  |
  68  |      0. |  0 |        0. |  0 |     0. |  0 |       0. |  0 |    0. |  0.0 |   0.0 |   0.0 |    0. |  0.0 |  0.0 | 0.0 | 0.0 | 0.0  |
  69  |      0. |  0 |        0. |  0 |     0. |  0 |       0. |  0 |    0. |  0.0 |   0.0 |   0.0 |    0. |  0.0 |  0.0 | 0.0 | 0.0 | 0.0  |
  70  |   2744. |  0 |   754000. |  0 |     0. |  0 |       0. |  0 |    0. | 27.7 |   0.0 |   0.0 |    0. |  0.0 | 3.15 | 0.0 | 0.0 | 0.0  |
  71  |   2444. |  0 |   626000. |  0 |     0. |  0 |       0. |  0 | 1472. | 22.1 |   0.0 |   0.0 | 1050. | 11.7 | 2.54 | 0.0 | 0.0 | 0.0  |
  72  |   5500. |  0 |  1510000. |  0 |     0. |  0 |       0. |  0 |    0. | 27.7 |   0.0 |   0.0 |    0. |  0.0 | 3.03 | 0.0 | 0.0 | 0.0  |
  73  |   5500. |  0 |  1432400. |  0 |     0. |  0 |       0. |  0 |    0. | 27.7 |   0.0 |   0.0 |    0. | 11.7 | [illegible] | 0.0 | 0.0 | 0.0  |
  74  |      0. |  0 |        0. |  0 |     0. |  0 |       0. |  0 |    0. |  0.0 |   0.0 |   0.0 |    0. |  0.0 |  0.0 | 0.0 | 0.0 | 0.0  |
  75  |      0. |  0 |        0. |  0 |     0. |  0 |       0. |  0 |    0. |  0.0 |   0.0 |   0.0 |    0. |  0.0 |  0.0 | 0.0 | 0.0 | 0.0  |
  76  |    149. |  0 |     8400. |  0 |     0. |  0 |       0. |  0 |    0. | 23.1 |   0.0 |   0.0 |    0. |  0.0 | 3.17 | 0.0 | 0.0 | 0.0  |
  77  |    102. |  0 |     3500. |  0 |     0. |  0 |      55. |  0 |  156. | 25.0 |   0.0 | 150.0 | 1040. | 34.9 | 1.40 | 0.0 | 0.0 | 0.0  |
  78  |    323. |  0 |        0. |  0 |     0. |  0 |       0. |  0 |  756. |  0.0 |   0.0 |   0.0 | 1050. |  0.0 |  0.0 | 0.0 | 0.0 | 0.0  |
  79  |      0. |  0 |        0. |  0 |     0. |  0 |       0. |  0 |    0. |  0.0 |   0.0 |   0.0 |    0. |  0.0 |  0.0 | 0.0 | 0.0 | 0.0  |
  80  |      0. |  0 |        0. |  0 |     0. |  0 |       0. |  0 |    0. |  0.0 |   0.0 |   0.0 |    0. |  0.0 |  0.0 | 0.0 | 0.0 | 0.0  |
  81  |      0. |  0 |        0. |  0 |     0. |  0 |       0. |  0 |    0. |  0.0 |   0.0 |   0.0 |    0. |  0.0 |  0.0 | 0.0 | 0.0 | 0.0  |
  82  |      0. |  0 |        0. |  0 |     0. |  0 |       0. |  0 |    0. |  0.0 |   0.0 |   0.0 |    0. |  0.0 |  0.0 | 0.0 | 0.0 | 0.0  |
  83  |      0. |  0 |        0. |  0 |     0. |  0 |       0. |  0 |    0. |  0.0 |   0.0 |   0.0 |    0. |  0.0 |  0.0 | 0.0 | 0.0 | 0.0  |
  84  |      0. |  0 |        0. |  0 |     0. |  0 |       0. |  0 |    0. |  0.0 |   0.0 |   0.0 |    0. |  0.0 |  0.0 | 0.0 | 0.0 | 0.0  |
  85  |      0. |  0 |        0. |  0 |     0. |  0 |       0. |  0 |    0. |  0.0 |   0.0 |   0.0 |    0. |  0.0 |  0.0 | 0.0 | 0.0 | 0.0  |
  86  |      0. |  0 |        0. |  0 |     0. |  0 |       0. |  0 |    0. |  0.0 |   0.0 |   0.0 |    0. |  0.0 |  0.0 | 0.0 | 0.0 | 0.0  |
  87  |      0. |  0 |        0. |  0 |     0. |  0 |       0. |  0 |    0. |  0.0 |   0.0 |   0.0 |    0. |  0.0 |  0.0 | 0.0 | 0.0 | 0.0  |
  88  |    130. |  0 |        0. |  0 |     0. |  0 |       0. |  0 |  393. |  0.0 |   0.0 |   0.0 | 1000. |  0.0 |  0.0 | 0.0 | 0.0 | 0.0  |
  89  |      0. |  0 |        0. |  0 |     0. |  0 |       0. |  0 |    0. |  0.0 |   0.0 |   0.0 |    0. |  0.0 |  0.0 | 0.0 | 0.0 | 0.0  |
  90  |      0. |  0 |        0. |  0 |     0. |  0 |       0. |  0 |    0. |  0.0 |   0.0 |   0.0 |    0. |  0.0 |  0.0 | 0.0 | 0.0 | 0.0  |
  91  |      0. |  0 |        0. |  0 |     0. |  0 |       0. |  0 |    0. |  0.0 |   0.0 |   0.0 |    0. |  0.0 |  0.0 | 0.0 | 0.0 | 0.0  |
  92  |      0. |  0 |        0. |  0 |     0. |  0 |       0. |  0 |    0. |  0.0 |   0.0 |   0.0 |    0. |  0.0 |  0.0 | 0.0 | 0.0 | 0.0  |
  93  |      0. |  0 |        0. |  0 |     0. |  0 |       0. |  0 |    0. |  0.0 |   0.0 |   0.0 |    0. |  0.0 |  0.0 | 0.0 | 0.0 | 0.0  |
  94  |      0. |  0 |        0. |  0 |     0. |  0 |       0. |  0 |    0. |  0.0 |   0.0 |   0.0 |    0. |  0.0 |  0.0 | 0.0 | 0.0 | 0.0  |
  95  |      0. |  0 |        0. |  0 |     0. |  0 |       0. |  0 |    0. |  0.0 |   0.0 |   0.0 |    0. |  0.0 |  0.0 | 0.0 | 0.0 | 0.0  |
```

FIGURE A-3 TYPICAL POINT SOURCE PRINTOUT FROM IBM INVENTORY (continued)

SOURCE NUMBER	SO2 EMISSIONS TONS/YEAR					PARTICULATE EMISSIONS TONS/YEAR					CONTROL EFFICIENCY		DEVICE IDENTIFICAT.
	COMPUTER CALCS.	HAND CALCS.	UNCON-TROLLED	CON-TROLLED	ALLOWABLE	COMPUTER CALCS.	HAND CALCS.	UNCON-TROLLED	CON-TROLLED	ALLOWABLE	PART.	SO2	
51	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.0	0.0	
52	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.0	0.0	
53	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.0	0.0	
54	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.0	0.0	
55	0.	240.	240.	240.	0.	0.	6.	6.	6.	0.	0.0	0.0	
56	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.0	0.0	
57	0.	0.	0.	0.	0.	0.	1344.	1344.	1344.	0.	0.0	0.0	
58	0.	0.	0.	0.	0.	0.	77.	77.	77.	0.	0.0	0.0	
59	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.0	0.0	
60	0.	235.	235.	235.	0.	0.	85.	85.	85.	0.	0.0	0.0	
61	0.	2340.	2340.	2340.	0.	0.	253.	253.	253.	0.	0.0	0.0	
62	0.	1070.	1070.	1070.	0.	0.	403.	403.	403.	0.	0.0	0.0	
63	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.0	0.0	
64	0.	0.	0.	0.	0.	0.	726.	726.	726.	0.	0.0	0.0	
65	0.	8640.	8640.	8640.	0.	0.	2662.	2662.	2662.	0.	0.0	0.0	
66	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.0	0.0	
67	0.	1495.	1495.	1495.	0.	0.	0.	0.	0.	0.	0.0	0.0	
68	0.	5580.	5580.	5580.	0.	0.	0.	0.	0.	0.	0.0	0.0	
69	0.	42.	42.	42.	0.	0.	17.	17.	17.	0.	0.0	0.0	
70	0.	43500.	43500.	43500.	0.	0.	788.	788.	788.	0.	0.0	0.0	
71	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.0	0.0	
72	0.	87300.	87300.	87300.	-4.	0.	2778.	2778.	2778.	0.	0.0	0.0	
73	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.0	0.0	
74	0.	0.	0.	0.	0.	0.	77.	77.	77.	0.	0.0	0.0	
75	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.0	0.0	
76	0.	507.	507.	507.	0.	0.	219.	219.	219.	0.	0.0	0.0	
77	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.0	0.0	
78	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.0	0.0	
79	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.0	0.0	
80	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.0	0.0	
81	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.0	0.0	
82	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.0	0.0	
83	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.0	0.0	
84	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.0	0.0	
85	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.0	0.0	
86	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.0	0.0	
87	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.0	0.0	
88	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.0	0.0	
89	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.0	0.0	
90	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.0	0.0	
91	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.0	0.0	
92	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.0	0.0	
93	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.0	0.0	
94	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.0	0.0	
95	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.0	0.0	

FIGURE A-3 TYPICAL POINT SOURCE PRINTOUT FROM IBM INVENTORY (concluded)

```
SOURCE NUMBER    3 REGION NUMBER 070POLITICAL JURISDICTION 10 COUNTY NAME ST.CHAS. COORDINATES  X 340.0 Y  800.0 AREA 400.0
           |   PARTICULATES    |   SULFUR OXIDES   |  CARBON MONOXIDE  |    HYDROCARBONS   |   NITROUS OXIDES  |    FUEL TOTAL     |
           |  ACTUAL | EXPECTED|  ACTUAL | EXPECTED|  ACTUAL | EXPECTED|  ACTUAL | EXPECTED|  ACTUAL | EXPECTED|  ACTUAL | EXPECTED|
DOMESTIC
COAL            0.                  0.                  0.                  0.                  0.                  0.
OIL             0.                  0.                  0.                  0.                  0.                  1.
NATL.GAS        0.                  0.                  0.                  0.                  1.                 21.
COMMEINC
COAL            0.                  0.                  0.                  0.                  0.                  0.
RES.OIL         0.                  0.                  0.                  0.                  0.                  0.
DIST.OIL        0.                  0.                  0.                  0.                  0.                  6.
NATL.GAS        0.                  0.                  0.                  0.                  0.                  2.
NON-PT
COAL            0.                  0.                  0.                  0.                  0.                  0.
RES.OIL         0.                  0.                  0.                  0.                  0.                  0.
DIST.OIL        0.                  0.                  0.                  0.                  0.                  5.
NATL.GAS        0.                  0.                  0.                  0.                  0.                  2.
WOOD            0.                  0.                  0.                  0.                  0.                  0.
OPEN BRN        2.                  0.                 11.                  4.                  1.                268.
INCINER         0.                  0.                  0.                  0.                  0.                  0.
SOLVENT         0.                  0.                  0.                  1.                  0.                  1.
VESSELS         0.                  0.                  0.                  0.                  0.                  0.
RAILRD          0.                  0.                  0.                  0.                  0.                  0.
DIESEL          0.                  1.                  4.                  1.                  4.                 25.
OTHER           0.                  0.                  0.                  3.                  0.                293.
AS 25MPH        1.                  1.                390.                 64.                 37.               3736.
AS 45MPH        0.                  0.                  0.                  0.                  0.                  0.
OTHER           0.                  0.                  0.                  0.                  0.                  0.
ADDPOL
   1            0.                  0.                  0.                  0.                  0.
   2            0.                  0.                  0.                  0.                  0.
   3            0.                  0.                  0.                  0.                  0.
   4            0.                  0.                  0.                  0.                  0.
   5            0.                  0.                  0.                  0.                  0.
   6            0.                  0.                  0.                  0.                  0.
   7            0.                  0.                  0.                  0.                  0.
   8            0.                  0.                  0.                  0.                  0.
   9            0.                  0.                  0.                  0.                  0.
  10            0.                  0.                  0.                  0.                  0.
  11            0.                  0.                  0.                  0.                  0.
  12            0.                  0.                  0.                  0.                  0.
  13            0.                  0.                  0.                  0.                  0.
  14            0.                  0.                  0.                  0.                  0.
  15            0.                  0.                  0.                  0.                  0.
```

FIGURE A-4   TYPICAL EMISSION SUMMARY BY COUNTIES FROM IBM INVENTORY

SUMMARY OF AIR POLLUTANT EMISSIONS
IN STUDY AREA, TONS/YEAR

SOURCE CATEGORY	SOX	PART	CO	HC	NOX
TRANSPORTATION					
ROAD VEHICLES	5182.	5746.	1036221.	79437.	63543.
OTHER	2089.	3038.	8850.	7737.	3159.
SUB-TOTAL	7272.	8794.	1045071.	87174.	66701.
COMBUSTION OF FUELS					
INDUSTRY	146159.	67090.	3024.	3459.	31717.
STEAM-ELECTRIC	447427.	54433.	3827.	1353.	109623.
RESIDENTIAL	12425.	3041.	5237.	1330.	3978.
COMM AND INST.	9679.	5438.	691.	268.	2574.
SUB-TOTAL	615688.	130002.	12778.	6409.	147842.
REFUSE DISPOSAL					
INCINERATION	561.	2403.	2678.	945.	1004.
OPEN BURNING	216.	3456.	19360.	6490.	1296.
SUB-TOTAL	777.	5959.	21038.	7425.	2300.
PROCESS	122425.	41265.	338581.	25479.	1763.
EVAP LOSSES				61169.	
GRAND TOTAL	746162.	185909.	1417465.	187655.	218606.

FIGURE A-5 SUMMARY OF AIR POLLUTANT EMISSIONS FOR THE STUDY AREA FROM THE NATO INVENTORY

SUMMARY OF AIR POLLUTANT EMISSIONS
IN ST LOUIS CIT COUNTY
TONS/YEAR

SOURCE CATEGORY	SOX	PART	CO	HC	NOX
TRANSPORTATION					
ROAD VEHICLES	1436.	1592.	287144.	22013.	17608.
OTHER	349.	188.	386.	279.	416.
SUB-TOTAL	1785.	1780.	287531.	22291.	18024.
COMBUSTION OF FUELS					
INDUSTRY	38829.	22130.	820.	743.	6288.
STEAM-ELEC	14479.	2032.	127.	39.	2289.
RESIDENTIAL	3829.	930.	1600.	406.	1194.
COMM AND INST	3511.	3455.	162.	92.	1465.
REFUSE DISPOSAL					
INCINERATION	274.	1066.	768.	372.	431.
OPEN BURNING	50.	800.	4250.	1500.	300.
SUB/TOTAL	324.	1866.	5018.	1872.	731.
PROCESS	1642.	18035.	183.	782.	26.
EVAP LOSSES				21429.	
GRAND TOTAL	64399.	50229.	295441.	47653.	30015.

FIGURE A-6 SUMMARY OF AIR POLLUTANT EMISSIONS, SAINT LOUIS CITY, MISSOURI, FROM THE NATO INVENTORY

COMBUSTION OF FUELS IN STATIONERY SOURCES
IN THE STUDY AREA
(TONS/YEAR)

FUEL	USER CATEGORY	SOX	PART	CO	HC	NOX
COAL						
	INDUSTRIAL	114296.	63589.	2979.	298.	14109.
	STEAM-ELECTRIC	445736.	54321.	3325.	1147.	107303.
	RESIDENTIAL	10345.	1666.	4165.	933.	416.
	COMM AND INST	9275.	5044.	454.	140.	328.
FUEL OIL						
	INDUSTRIAL	31927.	2553.	23.	343.	9371.
	STEAM-ELECTRIC	1689.	45.	0.	28.	584.
	RESIDENTIAL	1958.	680.	342.	206.	816.
	COMM AND INST	398.	172.	2.	34.	916.
GAS						
	INDUSTRIAL	32.	950.	21.	2111.	9237.
	STEAM-ELECTRIC	3.	57.	2.	178.	1736.
	RESIDENTIAL	22.	696.	732.	293.	2745.
	COMM AND INST	7.	223.	235.	94.	880.
GRAND TOTAL		615695.	130004.	12779.	6409.	147842.

FIGURE A-7 COMBUSTION OF FUELS BY STATIONARY SOURCES FROM THE NATO INVENTORY

ANNUAL FUEL CONSUMPTION

FUEL	JURISDICTION	STEAM-ELECTRIC	INDUSTRY	COMMERCIAL	RESIDENTIAL	TOTAL	FUEL CODE
1	ST LOUIS CIT	254000.	492000.	50000.	51100.	847100.	
1	ST LOUIS CO	2407000.	266000.	45000.	5110.	2723110.	1-COAL (TONS/YR)
1	JEFFERSON	0.	99000.	10000.	0.	99000.	
1	ST CHARLES	2079000.	0.	0.	0.	2079000.	
1	FRANKLIN	0.	0.	0.	5110.	5110.	
1	MADISON	2642000.	600000.	20000.	50078.	3312077.	
1	MONROE	0.	0.	0.	5110.	5110.	
1	ST CLAIR	267000.	440000.	25000.	50078.	782078.	
	TOTALS	7649000.	1897000.	150000.	166586.	9852591.	
2	ST LOUIS CIT	42.	0.	19200.	42924.	62166.	
2	ST LOUIS CO	0.	0.	1800.	35040.	36840.	2-DIST. OIL (1000 GAL/YR)
2	JEFFERSON	0.	0.	10.	113.	123.	
2	ST CHARLES	210.	0.	30.	4380.	4620.	
2	FRANKLIN	0.	0.	0.	10512.	10512.	
2	MADISON	320.	0.	270.	17169.	17759.	
2	MONROE	0.	0.	0.	2628.	2628.	
2	ST CLAIR	0.	0.	810.	23179.	23989.	
	TOTALS	572.	0.	22120.	135945.	158637.	
3	ST LOUIS CIT	0.	30000.	0.	0.	30000.	
3	ST LOUIS CO	0.	24000.	0.	0.	24000.	3-RESID. OIL (1000 GAL/YR)
3	JEFFERSON	0.	4500.	0.	0.	4500.	
3	ST CHARLES	0.	70.	0.	0.	70.	
3	FRANKLIN	0.	0.	0.	0.	0.	
3	MADISON	460.	137000.	0.	0.	137460.	
3	MONROE	0.	0.	0.	0.	0.	
3	ST CLAIR	10100.	7600.	0.	0.	17700.	
	TOTALS	10560.	203170.	0.	0.	213730.	
4	ST LOUIS CIT	0.	19500.	9900.	21559.	50958.	
4	ST LOUIS CO	2326.	9650.	9100.	34929.	56005.	4-NAT. GAS (MIL CU FT/YR)
4	JEFFERSON	0.	10500.	30.	73.	10603.	
4	ST CHARLES	0.	160.	30.	3111.	3301.	
4	FRANKLIN	0.	0.	10.	947.	957.	
4	MADISON	6579.	59000.	2100.	6363.	74042.	

FIGURE A-8 ANNUAL FUEL CONSUMPTION BY COUNTIES FROM THE NATO INVENTORY

POPULATION AND HOUSING UNITS

GRID	HC	VC	AREA	POPULATION	PEOPLE PER SQ KM	HU COAL	HU OIL	HU GAS	TOTAL HU
1	2250	8050	32.43	2146.	66.	0.	107.	494.	601.
2	3250	8050	32.43	1968.	61.	0.	98.	453.	551.
3	3500	8100	14.29	2370.	166.	0.	119.	545.	664.
4	4250	8250	32.43	847.	26.	0.	42.	195.	237.
5	4500	8200	14.29	825.	58.	0.	41.	190.	231.
6	4950	8350	32.43	13391.	413.	515.	1030.	2472.	4017.
7	5150	8350	32.43	8804.	271.	339.	677.	1625.	2641.
8	5450	8350	32.43	5874.	181.	226.	452.	1084.	1762.
9	5750	8350	32.43	1551.	48.	60.	119.	286.	465.
10	6050	8350	32.43	4361.	134.	168.	335.	805.	1308.
11	6350	8350	32.43	1200.	37.	47.	93.	223.	363.
12	2700	7800	14.29	4887.	342.	0.	244.	1124.	1368.
13	2250	7750	32.43	2243.	69.	0.	112.	516.	628.
14	3250	7750	32.43	4960.	153.	0.	248.	1141.	1389.
15	3500	7800	14.29	5516.	386.	0.	275.	1269.	1544.
16	3700	7800	14.29	2290.	160.	0.	114.	526.	641.
17	3500	7700	14.29	3195.	224.	0.	160.	735.	895.
18	3700	7700	14.29	4299.	301.	0.	215.	989.	1204.
19	3950	7950	32.43	7704.	238.	0.	385.	1772.	2157.
20	4250	7950	32.43	9119.	281.	7.	390.	2163.	2560.
21	3900	7700	14.29	12871.	901.	0.	644.	2960.	3604.
22	4100	7700	14.29	25660.	1796.	2.	1258.	5927.	7187.
23	4300	7700	14.29	22576.	1580.	23.	903.	5418.	6344.
24	4500	8000	14.29	3451.	242.	3.	143.	823.	969.
25	4750	8050	32.43	3870.	119.	53.	223.	836.	1111.
26	4450	7850	3.59	4205.	1171.	4.	169.	1009.	1182.
27	4550	7850	3.59	6654.	1853.	7.	266.	1597.	1870.
28	4650	7850	3.59	916.	255.	1.	37.	220.	257.
29	4750	7850	3.59	1291.	360.	1.	52.	310.	363.
30	4850	7850	3.59	804.	224.	1.	32.	193.	226.
31	4450	7750	3.59	9656.	2690.	10.	386.	2318.	2713.
32	4550	7750	3.59	15780.	4395.	16.	631.	3787.	4434.
33	4650	7750	3.59	8200.	2284.	8.	327.	1969.	2304.
34	4750	7750	3.59	2555.	712.	3.	102.	614.	718.
35	4850	7750	3.59	5900.	1643.	6.	236.	1416.	1658.
36	4450	7650	3.59	13937.	3881.	14.	557.	3345.	3916.
37	4550	7650	3.59	20576.	5730.	21.	833.	4938.	5792.
38	4650	7650	3.59	19561.	5449.	20.	782.	4690.	5491.
39	4750	7650	3.59	14751.	4108.	15.	590.	3540.	4145.
40	4950	7650	3.59	14035.	3909.	14.	561.	3368.	3944.
41	4950	8150	3.59	15363.	4279.	591.	1182.	2836.	4609.
42	5050	8150	3.59	12655.	3524.	407.	973.	2336.	3716.
43	4950	8050	3.59	220.	61.	5.	14.	45.	64.
44	5050	8050	3.59	491.	137.	17.	36.	93.	146.
45	5200	8100	14.29	32812.	2297.	1262.	2524.	6058.	9844.
46	5050	7850	32.43	11349.	350.	199.	642.	2443.	3284.

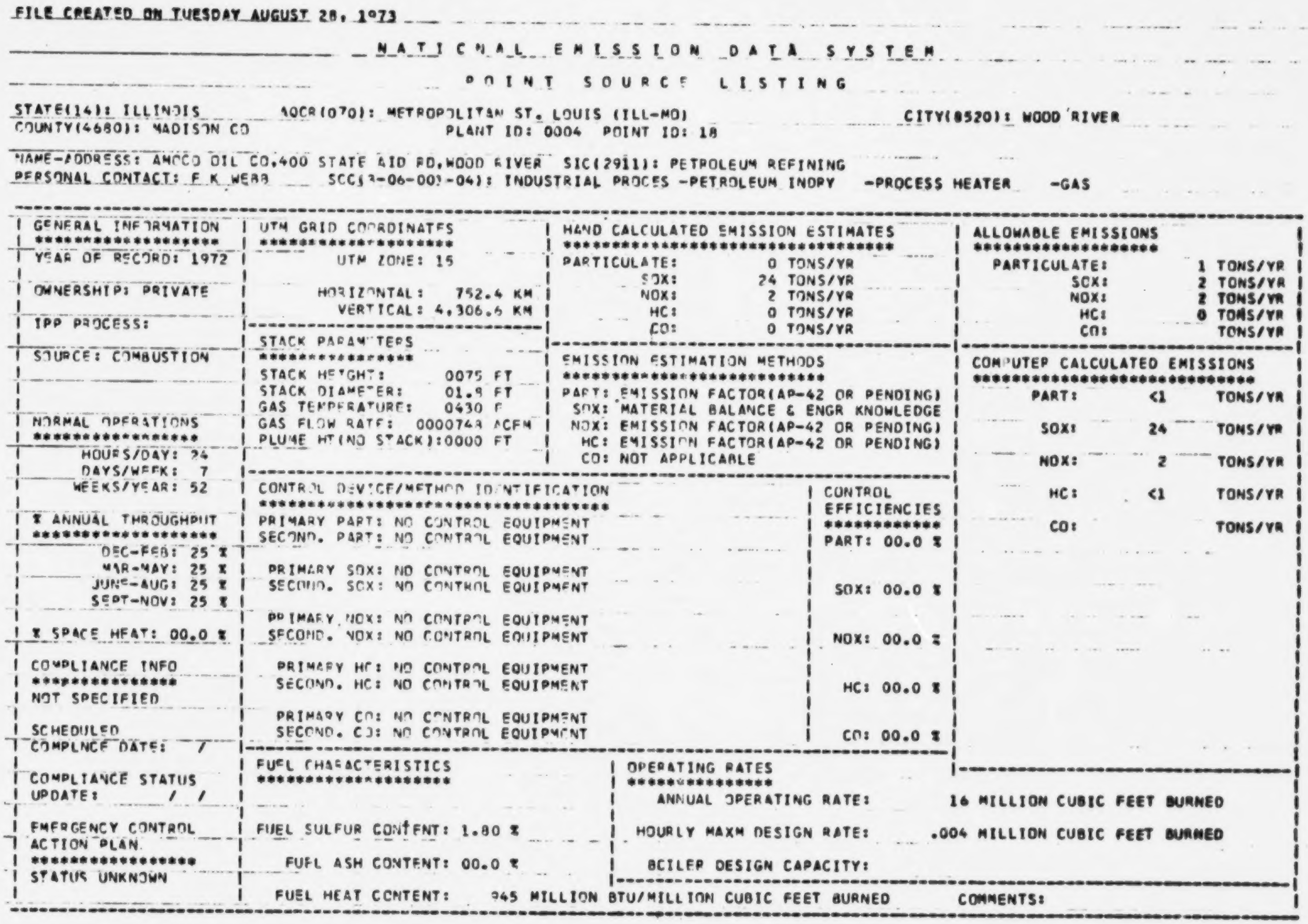
FIGURE A-9 POPULATION AND HOUSING UNITS BY GRIDS FROM THE NATO INVENTORY

9

EMISSION DENSITIES
TONS/SQ KM

		SOX			PART			CO			HC			NOX		
GRID	AREA	S	W	A	S	W	A	S	W	A	S	W	A	S	W	A
1	32.4	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.05	0.06	0.01	0.01	0.01	0.00	0.00	0.00
2	32.4	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.06	0.06	0.01	0.01	0.01	0.00	0.00	0.00
3	14.3	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
4	32.4	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.05	0.05	0.01	0.01	0.01	0.00	0.00	0.00
5	14.3	25.81	25.81	21.21	0.10	0.10	0.09	0.40	0.36	0.35	0.09	0.09	0.08	13.35	13.35	10.98
6	32.4	0.00	0.05	0.02	0.00	0.01	0.01	0.41	0.37	0.39	0.06	0.05	0.05	0.03	0.03	0.03
7	32.4	0.00	0.03	0.01	0.00	0.01	0.00	0.03	0.03	0.03	0.01	0.01	0.01	0.00	0.01	0.00
8	32.4	0.00	0.02	0.01	0.00	0.00	0.00	0.06	0.06	0.06	0.01	0.01	0.01	0.00	0.01	0.00
9	32.4	0.00	0.01	0.00	0.00	0.00	0.00	0.02	0.02	0.02	0.00	0.00	0.00	0.00	0.00	0.00
10	32.4	0.00	0.02	0.01	0.00	0.01	0.00	0.28	0.25	0.26	0.04	0.03	0.04	0.02	0.02	0.02
11	32.4	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.07	0.07	0.01	0.01	0.01	0.00	0.00	0.00
12	14.3	0.00	0.00	0.00	0.00	0.00	0.00	0.26	0.22	0.24	0.04	0.03	0.03	0.02	0.02	0.02
13	32.4	0.00	0.00	0.00	0.00	0.00	0.00	0.34	0.29	0.31	0.04	0.04	0.04	0.02	0.02	0.02
14	32.4	0.00	0.00	0.00	0.00	0.00	0.00	0.36	0.31	0.34	0.05	0.04	0.04	0.02	0.02	0.02
15	14.3	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.10	0.10	0.02	0.02	0.02	0.01	0.01	0.01
16	14.3	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.02	0.00	0.00	0.00	0.00	0.00	0.00
17	14.3	0.00	0.00	0.00	0.01	0.01	0.01	0.78	0.67	0.72	0.10	0.09	0.09	0.05	0.04	0.05
18	14.3	0.00	0.00	0.00	0.01	0.01	0.01	0.75	0.64	0.69	0.10	0.08	0.09	0.05	0.04	0.04
19	32.4	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.03	0.03	0.01	0.01	0.01	0.00	0.01	0.00

FIGURE A-10 EMISSION DENSITIES FROM THE NATO INVENTORY (tons/km^2)



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FILE CREATED ON TUESDAY AUGUST 28, 1973

                              N A T I O N A L   E M I S S I O N   D A T A   S Y S T E M

                                        P O I N T   S O U R C E   L I S T I N G

STATE(14): ILLINOIS         AQCR(070): METROPOLITAN ST. LOUIS (ILL-MO)                        CITY(8520): WOOD RIVER
COUNTY(4680): MADISON CO                           PLANT ID: 0004  POINT ID: 18

NAME-ADDRESS: AMOCO OIL CO,400 STATE AID RD,WOOD RIVER  SIC(2911): PETROLEUM REFINING
PERSONAL CONTACT: F K WEBB      SCC(3-06-001-04): INDUSTRIAL PROCES -PETROLEUM INDRY   -PROCESS HEATER   -GAS

-----------------------------------------------------------------------------------------------------------------------
| GENERAL INFORMATION  | UTM GRID COORDINATES        | HAND CALCULATED EMISSION ESTIMATES  | ALLOWABLE EMISSIONS                |
| ******************** | *********************       | *********************************** | ********************               |
| YEAR OF RECORD: 1972 |         UTM ZONE: 15        | PARTICULATE:         0 TONS/YR      |   PARTICULATE:        1 TONS/YR    |
|                      |                             |         SOX:        24 TONS/YR      |           SOX:        2 TONS/YR    |
| OWNERSHIP: PRIVATE   |     HORIZONTAL:   752.4 KM  |         NOX:         2 TONS/YR      |           NOX:        2 TONS/YR    |
|                      |       VERTICAL: 4,306.6 KM  |          HC:         0 TONS/YR      |            HC:        0 TONS/YR    |
| IPP PROCESS:         |-----------------------------|          CO:         0 TONS/YR      |            CO:          TONS/YR    |
|                      | STACK PARAMETERS            |-------------------------------------|------------------------------------|
| SOURCE: COMBUSTION   | *****************           | EMISSION ESTIMATION METHODS         | COMPUTER CALCULATED EMISSIONS      |
|                      | STACK HEIGHT:      0075 FT  | *****************************       | ****************************       |
|                      | STACK DIAMETER:    01.9 FT  | PART: EMISSION FACTOR(AP-42 OR PENDING) |      PART:      <1     TONS/YR |
|                      | GAS TEMPERATURE:   0430 F   |  SOX: MATERIAL BALANCE & ENGR KNOWLEDGE |                                 |
| NORMAL OPERATIONS    | GAS FLOW RATE:  0000748 ACFM|  NOX: EMISSION FACTOR(AP-42 OR PENDING) |       SOX:      24     TONS/YR |
| ******************   | PLUME HT(NO STACK):0000 FT  |   HC: EMISSION FACTOR(AP-42 OR PENDING) |                                 |
|      HOURS/DAY: 24   |                             |   CO: NOT APPLICABLE                |       NOX:       2     TONS/YR |
|      DAYS/WEEK:  7   |-----------------------------------------------------------------|                                 |
|     WEEKS/YEAR: 52   | CONTROL DEVICE/METHOD IDENTIFICATION        | CONTROL           |        HC:      <1     TONS/YR |
|                      | ************************************        | EFFICIENCIES      |                                 |
| % ANNUAL THROUGHPUT  | PRIMARY PART: NO CONTROL EQUIPMENT          | ************      |        CO:             TONS/YR |
| ******************** | SECOND. PART: NO CONTROL EQUIPMENT          | PART: 00.0 %      |                                 |
|        DEC-FEB: 25 % |                                             |                   |                                 |
|        MAR-MAY: 25 % |  PRIMARY SOX: NO CONTROL EQUIPMENT          |                   |                                 |
|       JUNE-AUG: 25 % |  SECOND. SOX: NO CONTROL EQUIPMENT          |  SOX: 00.0 %      |                                 |
|       SEPT-NOV: 25 % |                                             |                   |                                 |
|                      |  PRIMARY NOX: NO CONTROL EQUIPMENT          |                   |                                 |
| % SPACE HEAT: 00.0 % |  SECOND. NOX: NO CONTROL EQUIPMENT          |  NOX: 00.0 %      |                                 |
|                      |                                             |                   |                                 |
| COMPLIANCE INFO      |   PRIMARY HC: NO CONTROL EQUIPMENT          |                   |                                 |
| ***************      |   SECOND. HC: NO CONTROL EQUIPMENT          |   HC: 00.0 %      |                                 |
| NOT SPECIFIED        |                                             |                   |                                 |
|                      |   PRIMARY CO: NO CONTROL EQUIPMENT          |                   |                                 |
| SCHEDULED            |   SECOND. CO: NO CONTROL EQUIPMENT          |   CO: 00.0 %      |                                 |
| COMPLNCE DATE:   /   |-----------------------------------------------------------------|                                 |
|                      | FUEL CHARACTERISTICS             | OPERATING RATES                  |---------------------------------|
| COMPLIANCE STATUS    | ********************             | ***************                                                    |
| UPDATE:      / /     |                                  |   ANNUAL OPERATING RATE:        16 MILLION CUBIC FEET BURNED      |
|                      |                                  |                                                                    |
| EMERGENCY CONTROL    | FUEL SULFUR CONTENT: 1.80 %      |  HOURLY MAXM DESIGN RATE:     .004 MILLION CUBIC FEET BURNED      |
| ACTION PLAN          |                                  |                                                                    |
| ***************      |   FUEL ASH CONTENT: 00.0 %       |   BOILER DESIGN CAPACITY:                                          |
| STATUS UNKNOWN       |                                  |--------------------------------------------------------------------|
|                      |  FUEL HEAT CONTENT:    945 MILLION BTU/MILLION CUBIC FEET BURNED      COMMENTS:                   |
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FIGURE A-11   NATIONAL EMISSION DATA SYSTEM POINT SOURCE LISTING

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FILE CREATED ON TUESDAY AUGUST 28, 1973

                        N A T I O N A L   E M I S S I O N   D A T A   S Y S T E M

                             CONDENSED POINT SOURCE LISTING FOR PARTICULATE
                                   FOR ALL VALUES > THAN OR = TO        0
                                   EMISSIONS ARE IN SHORT TONS PER YEAR

                                                                            PART    S O X    N O X    H C     C O

0001: COATES STEEL PROD.W FRANKLIN,GRNVLE62246         OWNERSHIP: PRIVATE
14: ILLINOIS         0520: BOND                        YEAR OF RECORD:  1970
070: METROPOLITAN ST. LOUIS (ILL-MO)
000: NO CONTROL EQUIPMENT                      EFF =      % POINT: 01
ESTIMATE BY (3) USED EMISSIONS FACTORS    SIC = 3312  SCC = 3-04-007-04

0001: COATES STEEL PROD.W FRANKLIN,GRNVLE62246         OWNERSHIP: PRIVATE
14: ILLINOIS         0520: BOND                        YEAR OF RECORD:  1970
070: METROPOLITAN ST. LOUIS (ILL-MO)
000: NO CONTROL EQUIPMENT                      EFF =      % POINT: 01
ESTIMATE BY (3) USED EMISSIONS FACTORS    SIC = 3312  SCC = 3-90-005-99

0001: COATES STEEL PROD.W FRANKLIN,GRNVLE62246         OWNERSHIP: PRIVATE
14: ILLINOIS         0520: BOND                        YEAR OF RECORD:  1970
070: METROPOLITAN ST. LOUIS (ILL-MO)
000: NO CONTROL EQUIPMENT                      EFF =      % POINT: 01
ESTIMATE BY (3) USED EMISSIONS FACTORS    SIC = 3312  SCC = 3-90-005-99

0001: BUEHNE QUARRY CO RT 1 ST ROSE TWN  62230         OWNERSHIP: PRIVATE               39
14: ILLINOIS         1440: CLINTON                     YEAR OF RECORD:  1970
070: METROPOLITAN ST. LOUIS (ILL-MO)
000: NO CONTROL EQUIPMENT                      EFF =      % POINT: 01
ESTIMATE BY (5) SPECIAL EMISSION FACTOR   SIC = 1441  SCC = 3-05-020-02

0001: BUEHNE QUARRY CO RT 1 ST ROSE TWN  62230         OWNERSHIP: PRIVATE               13
14: ILLINOIS         1440: CLINTON                     YEAR OF RECORD:  1970
070: METROPOLITAN ST. LOUIS (ILL-MO)
000: NO CONTROL EQUIPMENT                      EFF =      % POINT: 01
ESTIMATE BY (5) SPECIAL EMISSION FACTOR   SIC = 1441  SCC = 3-05-020-01

0003: NEW BADEN GRAIN CO 12 W MILL ST    62265         OWNERSHIP: PRIVATE                3
14: ILLINOIS         1440: CLINTON                     YEAR OF RECORD:  1972
070: METROPOLITAN ST. LOUIS (ILL-MO)
   : NO CONTROL EQUIPMENT                      EFF =      % POINT: 03
ESTIMATE BY ( )  CODE NOT APPLICABLE      SIC = 2041  SCC = 3-02-007-01
```

FIGURE A-12 NATIONAL EMISSION DATA SYSTEM CONDENSED POINT SOURCE LISTING FOR PARTICULATE FOR ALL VALUES GREATER THAN OR EQUAL TO ZERO

Appendix B

SUMMARY OF EMISSION MODEL REPORTS

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INTRODUCTION

In this Appendix we have reviewed and summarized twenty-seven reports on the treatment and parameterization of man-made emissions. These summaries are intended to provide the potential user with a concise overview of the scope and content of each of the models. Each summary identifies the author and his or her affiliation, includes the author's abstract, and provides a synopsis of the emission model methodology together with a statement of the model's format and availability.

For convenience, the reports are listed alphabetically by affiliation. The depth and merit of the various models are reflected in the summaries. While our review is extensive, it should not be interpreted as all inclusive. Many reports were reviewed initially and later deleted from this final listing either because they were of no direct use to RAPS or because the methods they contained were more appropriately documented or developed elsewhere.

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I ARGONNE NATIONAL LABORATORY

Chicago Air Pollution Systems Analysis Program: A Multiple-Source Urban Atmospheric Dispersion Model. J. J. Roberts, E. J. Croke, A. S. Kennedy, J. E. Norco, and L. A. Conley, Argonne Natl. Lab. Rept. No. ES-CC-007, prepared for Chicago Dept. of Environmental Control and National Air Pollution Control Administration, May, 1970.

A. Author's Abstract

This report is a comprehensive documentation of the dispersion-model development phase of the Chicago Air Pollution Systems Analysis Program. A multiple-source, urban atmospheric dispersion model has been developed which described transients such as morning transitions in atmospheric stability and mixing layer height. The dispersion model has been validated by comparison with over 10,000 hourly averages of sulfur dioxide monitored by the Department of Environmental Control of the City of Chicago. For example, the model accounts for 50% of the variance in 6-hr averages of observed data and 70% of the variance in 24-hr averages. Of particular significance in the capability of the model to describe "area sources" as volumetric clouds of pollutant and thus to evaluate the effect of these sources on dose points within, as well as external to, the area.

The atmospheric transport kernel in the model describes the instantaneous release (delta function) of pollutant, advection according to piecewise constant hourly wind vectors, and Gaussian diffusion about the centroid. Continuous plumes are simulated by integration in time of this point-source Green's function.

This report details the transport theory and all other computerized algorithms that influence the dispersion problem and presents statistical results of extensive validation studies.

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B. Summary

An inventory of average hourly emissions of sulfur dioxide was developed for power plants and industrial, residential, commercial, and institutional sources in the Chicago area. Hourly SO_2 emissions from power plants were derived from actual power output logs; hourly emissions from other sources were obtained through reduction of annual fuel-use data according to seasonal and diurnal patterns. Major emitters were considered individually as point sources, with the remaining emissions grouped into area sources.

1. Treatment of Area Sources

The area source overlay grid is input to the model. It is specified by five parameters: the x, y coordinates of the origin, the number of grid squares in the x and y directions, and the length of the side of each grid square. The grid used in the validation computation consisted of 1.0x1.0-mile squares at the center of the array, with surrounding 2.0x2.0-mile, then 4.0x4.0-mile grid squares.

Representative pollutant emission rates and stack heights are assigned to each grid square for each source: (1) low-rise space heaters; (2) high-rise space heaters; and (3) industry.

a. Low-rise Residential and Commercial Emissions

Hourly emissions from low-rise residential and commercial sources are assumed to be proportional to the number of heating degree days, with a fixed fraction of annual emissions uniformly prorated to hot water heating. The heating cycle is assumed to occur between the hours TON and TOFF, with emissions equal to the hot water rate at all other times. A "janitor function" is synthesized to account for the greater than usual fuel demand during the first two hours of the heating day. Hourly emissions are given by

$$Q_{heating} = \frac{Q_{annual}\ (1\text{-PCTHW})\ (65\text{-TEMP})\ TE}{DDAVG\ (TONOFF)} \qquad \begin{array}{l} TEMP \le 65^{o}F \text{ and} \\ TON \le \text{time of day} \\ \quad \le TOFF \end{array}$$

$$Q_{hot\ water} = \frac{Q_{annual}\ (PCTHW)}{8760}$$

$$Q_{total} = Q_{heating} + Q_{hot\ water}$$

where DDAVG = average number of degree days/year

PCTHW = fraction of annual fuel used for hot water

TEMP = hourly average temperature

TONOFF = TOFF - TON + 1

$$TE = \text{janitor function} = \begin{cases} 1.5 & TON \le \text{time of day} \le TON + 1 \\ 1.0 & TON + < \text{time of day} < TOFF \end{cases}$$

All moderate-sized residences were assigned a stack height of 50 feet.

b. High-rise Residential, Commercial and Institutional Emissions

These emissions are estimated using the above method, but with TON =1 and TOFF = 24. Physical stack height was assumed to be 200 feet.

Industrial Emissions. Industrial area source emissions are distributed uniformly over the calendar year:

$$Q_{hourly} = \frac{Q_{annual}}{8760}$$

2. Treatment of Point Sources

a. Power Plant Emissions

Actual hourly power output (MW) from Chicago power plants was used in the validation study of the model. The following power plant emission algorithms are proposed as the production version of the program.

For each season of the year, a graph is made of peak daily load versus average daily temperature. From these graphs the peak load is estimated as a linear function of temperature. Several daily charts of system load versus hour of the day, within a given season, are superimposed. Weekday patterns for summer and winter result, with spring and fall having two weekday patterns each that are distinguished by average daily temperature. Since little weekend data are usually available, a typical weekend pattern is used for all seasons. The patterns are stored as data statements containing 24 numbers, one for each hour of the day. Given the average daily temperature, the day of the week, and the season of the year, the hourly system load is calculated by subtracting the data statement of the appropriate hour from the peak load obtained from the graph of peak load versus temperature.

If individual unit load is plotted against total system load, functional relationships of the form

$$U = \begin{cases} b_1 & S < a_1 \\ b_1 + \left(b_2 - b_1\right)\left[\dfrac{S-a_1}{a_2-a_1}\right] & a_1 < S < a_2 \\ b_2 & S > a_2 \end{cases}$$

where U = individual unit load

S = system load

a_1, a_2, b_1, b_2 = coefficients derived from the graph

can be formulated for each unit, making it possible to obtain individual unit load from the previously calculated system load.

Graphs of utility company data give the variation of unit load with thermal input, and coefficients describing this variation are derived. Thermal input is given by

$$T = AL + B$$

where T = thermal input

L = unit load

A,B = derived coefficients

Hence, emission rates are determined:

$$\underset{(\text{lb/hr})}{SO_2 \text{ from coal}} = \frac{[T(\text{therms/hr})]\ [10^5\ \text{BTU/therm}]\ (\text{avg. annual \% coal used}]}{[12{,}000\ \text{BTU/lb}]\ [2000\ \text{lb/ton}]} \cdot \frac{[38.0]\ [\text{\% sulfur of coal}]}{[12{,}000\ \text{BTU/lb}]\ [2000\ \text{lb/ton}]}$$

$$\underset{(\text{kgal/hr})}{SO_2 \text{ from oil}} = \frac{[T(\text{therms/hr}]\ [10^5\ \text{BTU/therm}]\ [\text{avg. annual \% oil used}]}{[18{,}000\ \text{BTU/lb}]\ [8000\ \text{lb/kgal}]} \cdot \frac{[157]\ [\text{\% sulfur of oil}]}{[18{,}000\ \text{BTU/lb}]\ [8000\ \text{lb/kgal}]}$$

The thermal emission rate is given by

thermal emission rate = 0.12 T

To divide total thermal and SO_2 emission rates among the stacks, the percent of effluent handled by each stack is applied to the total rate.

b. Industrial Emissions

The fifty largest industrial source emitters are treated as point sources, with the remaining emissions aggregated into uniformly distributed square mile area sources. Plants in this category are assumed to have a stack height of 150 feet.

A detailed analysis of the diurnal, weekly, and seasonal operating patterns for each plant was performed, yielding factors by which the maximum process load is multiplied to obtain the process load at a given time.

$$L^P = \left(\begin{array}{c}\text{shift weighting}\\\text{factor}\end{array}\right)\left(\begin{array}{c}\text{monthly weighting}\\\text{factor}\end{array}\right) L^P_{MAX}$$

where L^P = process load

L^P_{MAX} = maximum process load

Shift factors are tabulated for weekdays, Saturdays, and Sundays or special holidays for each of the three shifts, 0000-0800, 0800-1600, and 1600-0000 local time. Monthly factors account for seasonal variations.

The space-heating thermal load is assumed to be linearly related to temperature.

$$L^s = L^s_{MAX} \frac{[55-T]}{65} \qquad -10 \leq T \leq 55$$

where L^s = space-heating thermal load

L^s_{MAX} = maximum space-heating thermal load

T = temperature

The total thermal load is

$$L = L^s + L^p = L^c + L^o$$

where L equals total thermal load and L^c and L^o are the portions of the thermal load due to coal and oil, respectively.

$$SO_2{}^c\ (\text{lb/hr}) = \frac{[L^c(\text{therms/hr})]\ [10^5\ \text{BTU/therm}]\ [36.8]\ [\%\ \text{sulfur of coal}]}{[12{,}000\ \text{BTU/lb}]\ [2000\ \text{lb/ton}]}$$

$$SO_2{}^o\ (\text{kgal/hr}) = \frac{[L^o(\text{therms/hr})]\ [10^5\ \text{BTU/therm}]\ [157]\ [\%\ \text{sulfur of oil}]}{[18{,}000\ \text{BTU/lb}]\ [8000\ \text{lb/kgal}]}$$

When a dual-fuel interruptible plant is receiving natural gas, the SO_2 emissions are correspondingly reduced.

Heat emissions are assumed to be 15% of the thermal input.

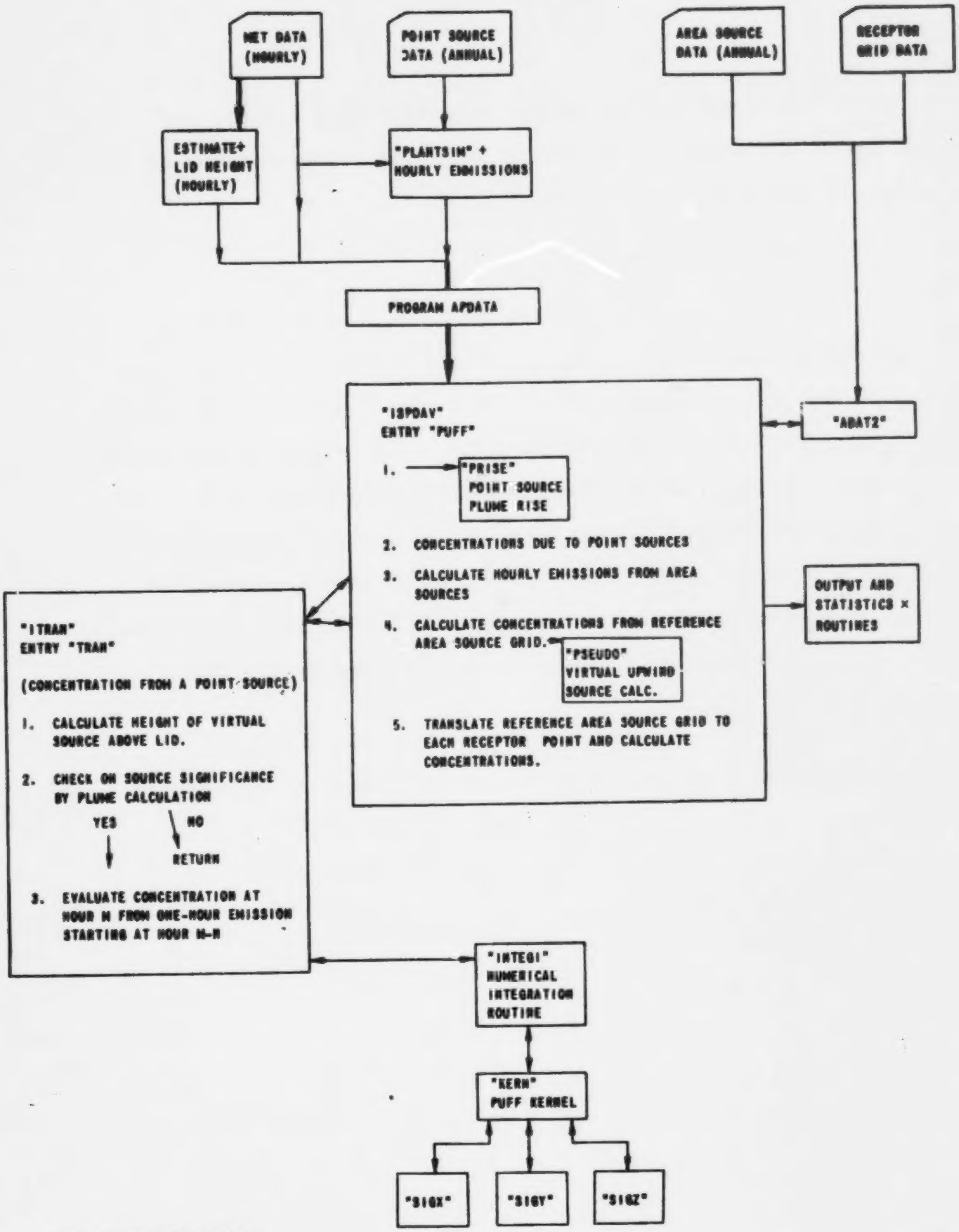
Heat and sulfur dioxide emissions from a plant are apportioned to its stacks by weighting the total emission rates by the percentage of effluent handled by each stack.

c. Additional Sources

Annual emission information from several additional point sources was stored in a subroutine of the dispersion model and prorated by appropriate program statements. These emissions were distributed using one of three source patterns: (1) uniform proration of annual output; (2) 24-hour degree day response, with 20% of fuel use prorated uniformly for hot water; and (3) a special diurnal pumping station pattern. The pumping station pattern allowed two levels of output, a high level between the hours 0600 and 2200, and a low level, about one-third of the daytime emission rate, at all other times.

C. Model Availability

A program listing of the Argonne emissions model is included in the report.


MET DATA (HOURLY)
POINT SOURCE DATA (ANNUAL)
AREA SOURCE DATA (ANNUAL)
RECEPTOR GRID DATA
ESTIMATE+ LID HEIGHT (HOURLY)
"PLANTSIN" + HOURLY EMMISSIONS
PROGRAM APDATA
"ISPDAV"
ENTRY "PUFF"
1.
"PRISE" POINT SOURCE PLUME RISE
2. CONCENTRATIONS DUE TO POINT SOURCES
3. CALCULATE HOURLY EMISSIONS FROM AREA SOURCES
4. CALCULATE CONCENTRATIONS FROM REFERENCE AREA SOURCE GRID.
"PSEUDO" VIRTUAL UPWIND SOURCE CALC.
5. TRANSLATE REFERENCE AREA SOURCE GRID TO EACH RECEPTOR POINT AND CALCULATE CONCENTRATIONS.
"ABAT2"
OUTPUT AND STATISTICS × ROUTINES
"ITRAN"
ENTRY "TRAN"
(CONCENTRATION FROM A POINT SOURCE)
1. CALCULATE HEIGHT OF VIRTUAL SOURCE ABOVE LID.
2. CHECK ON SOURCE SIGNIFICANCE BY PLUME CALCULATION
YES
NO
RETURN
3. EVALUATE CONCENTRATION AT HOUR N FROM ONE-HOUR EMISSION STARTING AT HOUR N-M
"INTEGI" NUMERICAL INTEGRATION ROUTINE
"KERN" PUFF KERNEL
"SIGX"
"SIGY"
"SIGZ"

× SEPARATE COMPUTER PROGRAMS

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FIGURE B-1 FLOW DIAGRAM FOR CALCULATION OF POLLUTION LEVELS

II ARGONNE NATIONAL LABORATORY

Transportation Air Pollutant Emissions Handbook. T. D. Wolsko, M.T. Matthies, and R. E. Wendell, Argonne National Laboratory, Argonne, Illinois, July, 1972.

A. Author's Abstract

The objective of this report is to describe a procedure that can be used to quantify the air pollutant emissions (carbon monoxide, hydrocarbons, nitrogen oxides) from transportation sources. The report is designed to enable someone not familiar with air pollution problems from transportation systems to quantify such emissions with the aid of the background information, emission data, computer program descriptions, and manual calculation procedures contained herein. Although emissions from transportation vehicles are not completely understood, the state-of-the-art of measuring air pollutant emissions from transportation sources is presented. This report will be revised if and when a more complete understanding of emissions from transportation sources evolves.

Section 1 provides a brief background on the sources of air pollution from transportation vehicles. The basic emission data used to calculate transportation emissions are described in Section 2. Two computer programs that can be used to calculate emissions are described in Section 3. The first program, TREFACT, calculates emission factors for widely varying vehicle characteristics and transportation system operation. The second program, TREMISS, uses regional transportation simulation data to calculate emissions for large transportation networks. Complete source listings of both programs are given in Appendix A.

Manual emission calculation procedures are illustrated by means of sample problems in Section 4. These procedures are designed to provide

a simple method for calculating air pollutant emissions from roadways. A fairly complete set of emission factors is tabulated in Appendix B, so that transportation emissions can be calculated without using either of the computer programs.

B. Summary

Two computer programs were written to relieve the environmental impact analyst of the emission calculation burden. The first program, TREFACT, calculates the emission rates for vehicles or mixes of vehicles based on vehicle usage (speed, vehicle miles, type of trip). The second program, TREMISS, was developed to calculate emissions for the complex traffic simulation grid used by urban regional transportation planners. The outputs from a typical regional traffic simulation model (origins, vehicle miles, speed) and TREFACT outputs are used to calculate grid-dependent emissions for the entire urban region. A detailed description of each of these programs is provided, along with input descriptions and sample problems. Complete listings of both programs are contained in an appendix.

The computer programs are used to calculate grid-dependent emissions for large urban transportation networks. A method for manually calculating air pollutant emissions from transportation sources is described in another section of the report. This method is designed to calculate emissions from individual transportation links (e.g., highways).

The emission factors calculated by TREFACT are for the standardized urban and rural speeds. TREMISS has speed adjustment data to modify the emission factors for the speed-dependent transportation network. The speed adjustment curves from the figures accompanying this summary have been transformed into a set of linear equations that will be used to adjust the emission calculations for individual roadways. Urban and rural speed adjustment factors should be used with urban and rural emission factors, respectively. It should be remembered that this speed adjustment data are representative of typical traffic and does not represent free-flowing traffic at that average speed.

TREFACT calculates emission factors for transportation systems with widely varying vehicle types and operating conditions. Emission factor can be calculated for any year between 1960-1990 for six classes of vehicles. A vehicle-class-weighted emission factor is also calculated. Options are available to include the effects of cold-start operation, retrofitting control devices on pre-1968 vehicles (Class 1 only), and consideration of diesel-powered vehicles.

Urban regional transportation planning involves an enormous computer traffic simulation system. The typical Chicago Area Transportation Study (CATS) traffic simulation network has approximately 1,800 transportation activity grids which cover the eight-county Chicago metropolitan area. A computer program was written to calculate grid-dependent air pollutant emissions (CO, HC, NO_x) from transportation sources for the CATS planning area. This program, TREMISS, uses output data files from the CATS traffic simulation model, but data from any traffic simulation program can be used.

Regional traffic simulations are quite costly and there may not always be data available for the study year. Therefore, TREMISS has the additional capability of linearly interpolating between simulation output data for two study years. This is extremely helpful when traffic data is not available for a particular year. TREMISS is structured to interpolate between 1965 and 1985 simulations for any intervening year.

Emissions can be calculated for each grid using either one set of "weighted" emission factors or six sets of emission factors, one for each class of vehicles. (Diesels [Class 6] may or may not be used in the calculation.) Additionally, the complete set of grids may be grouped into any number of subsets. Each such subset has its "own" set of emission factors. However, the mixing of "weighted" and "class" emission factors is not permitted.

Emission summaries for each grid and the totals for all grids are the major outputs. If class-dependent emission factors are used, summaries by class are also given. Emission summaries for any specified set of grids representing a county, municipality, or problem area (e.g., Cook County, Chicago, Chicago Business District) can also be calculated.

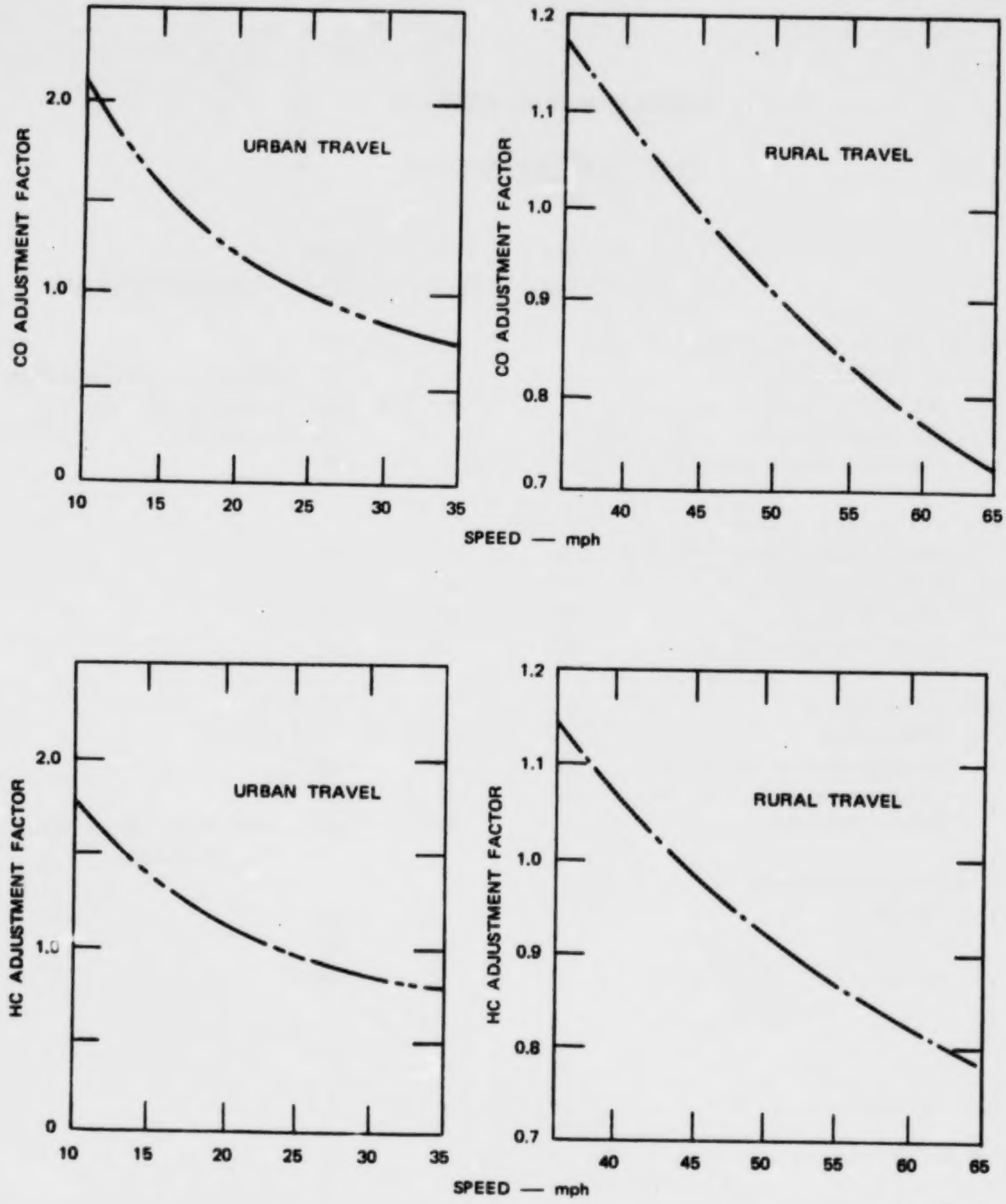

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FIGURE B-2 SPEED ADJUSTMENT FACTORS FOR HYDROCARBON EXHAUST EMISSION FACTORS AND CARBON MONOXIDE EMISSION FACTORS

EMISSION MODELS CHECKLIST

Input Data Requirements

	Within Program	User Supplies	From AP-42	Proxies/Comments
Vehicle Emission Factors				
-By model year	x	x	x	Factors available in report for use as desired
-By size class	x	x	x	
-By power plant	x	x	x	
-Deterioration factor	x	x	x	
Vehicle Operating Modes				
-Hot/cold start	x	x	NP	
-Route average	x	x	x	
-Link average	NP	NP	NP	
-Mode-by-mode	NP	NP	NP	
Traffic Features				
-Vehicle mix	x	x	x	
-Engine operating time	NP	NP	NP	
-Vehicle miles traveled	NP	NP	NP	
-Fuel consumed	x	NP	NP	For heavy duty truck calculations
Spatial Distribution				
-Links			NP	
-Grinds	x	x	NP	
-Area			NP	

NP = No provision

Output Available

Pollutants	
-CO	Yes
-HC	Yes
-NO_x	Yes
-Particulates	No

Availability of Program Documentation

	Yes	No
Included in report	x	
Referenced in report	x	
Language	FORTRAN ; PL/1	
Equipment	IBM	

Validation/calibration: Chicago area and EPA data

Time resolution: Hourly (peak/off-peak); daily

Spatial resolution: Subareas; grids

III AIR RESOURCES FIELD RESEARCH OFFICE, ESSA

The Diurnal and Day-to-Day Variations of Fuel Usage for Space-Heating in St. Louis, Missouri. D. B. Turner, Atmospheric Environment, 1968.

A. Author's Abstract

Data on the wintertime emissions of SO_2 from residential and commercial space-heating sources by 2-hr periods were needed for use in a diagnostic dispersion model. Analyses were made of hourly steam-output data from a centralized heating plant and hourly gas-sendout data for December 1964 at St. Louis, Mo., to determine dependence upon temperature and other factors. Methods were then developed to determine the rate of fuel use from residential and commercial space-heating sources for each hour of the day from values for the hourly temperature, the hour of the day, and the day of the week. Relations developed from December 1964 data were tested on data for January and February 1965.

B. Summary

1. Description of Algorithm

A mathematical representation of the diurnal and day-to-day variations of fuel consumption resulting from residential and commercial space heating was developed for St. Louis, Missouri. Available data included hourly temperatures and hourly gas and steam output rates. Steam output rates are taken as representative of commercial sources, and gas send-out rates are taken as representative of residential sources.

To obtain equations relating daily output and daily temperature, graphs were constructed to give the least-squares linear regressions for weekdays and weekends. For weekdays, 20 data pairs were used to give

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$$DS = 8.40 - 0.1078\ DT$$

$$DG = 30.00 - 0.3498\ DT$$

where DS = daily steam output rate

DG = daily gas send-out rate

DT = daily temperature

The effect of short-term temperature variation on the diurnal cycle of space heating was investigated by determining the deviation of the hourly temperature from the daily value for both gas and steam, and then averaging these deviations for each hour for all weekday data. Plots of both gas and steam deviations versus temperature deviation were made, and the finite difference forms of the daily send-out equations were applied to give output deviations with zero temperature deviation. These hourly values, calculated for weekdays, Saturdays (only four data days were used) and Sundays (only five data days were used), represent diurnal variation due to all causes other than temperature.

To make these variations applicable to other space heating sources, the values were divided by the slope of the regression line, thus converting to units of temperature. Saturday and Sunday values were adjusted so that the same total daily heat is required for a day with the same daily temperature, regardless of whether it is a Saturday, Sunday, or weekday.

Hourly steam output or gas-send-out is given by

$$A = a+b(T+H)$$

where A = hourly output

a,b = regression constants in daily output equations

T = hourly temperature

H = diurnal value (calculated above) for appropriate hour of day, day of week, gas or steam

It is assumed that no lag time exists between a change in temperature and its effect on space heating requirements.

2. Validation

The above equation was derived from data recorded in St. Louis during the month of December, 1964, and was used to calculate hourly output for January and February, 1965, for comparison with actual data. Error was measured in degrees Farenheit. For steam, 71% of the calculated values were less than 6^oF in error, and 95% were less than 12^oF in error. For an hour with a temperature of 30^oF, an error of 12^oF results in about 25% error in steam output.

Overall, 80% of the calculated data were within ± 7^oF of the actual values. The author states that this degree of accuracy is commensurate with the accuracy of the emission inventory. It is assumed that derived diurnal factors for gas will be nearly the same for oil and coal, and that steam factors will reflect patterns of commercial space-heating with any fuel.

C. Model Availability

A computerized treatment for calculation of hourly emission estimates is not referenced in the paper.

IV FEDERAL HIGHWAY ADMINISTRATION

APRACMØD, Modification of APRAC-1A. P. W. Blow, FHWA.

A. Author's Abstract

None given.

B. Summary

APRACMØD is a modified version of the APRAC-1A urban diffusion model reported on in A Practical, Multipurpose Urban Diffusion Model for Carbon Monoxide. The purpose of the model is to estimate carbon monoxide concentrations at arbitrary points in an urban region resulting from projected vehicular travel.

The APRAC-1A urban diffusion model was modified to accept a standard FHWA Urban Transportation Planning Battery BUILDHR data set with carbon monoxide emission words added on each link record as input rather than the link card inputs for APRAC-1A. The modification further allows more links to be processed than the original program.

The program is composed of 17 separate decks and is written in FORTRAN.

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EMISSION MODELS CHECKLIST

Input Data Requirements

	Within Program	User Supplies	From AP-42	Proxies/Comments
Vehicle Emission Factors				
-By model year	x	x		Average CO of vehicle mix for year of study interest
-By size class	x	x		
-By power plant	x	x		
-Deterioration factor	x	x		
Vehicle Operating Modes				
-Hot/cold start		NP		
-Route average		NP		
-Link average		x		Speed and Distance
-Mode-by-mode		NP	NP	
Traffic Features				
-Vehicle mix		NP		
-Engine operating time		NP	NP	
-Vehicle miles traveled		x	NP	
-Fuel consumed		NP	NP	
Spatial Distribution				
-Links		NP	NP	
-Grinds		x	NP	
-Area		x	NP	

NP = No provision

Output Available

Pollutants

-CO	Yes
-HC	No
$-NO_x$	No
-Particulates	No

Availability of Program Documentation

	Yes	No
Included in report	x	
Referenced in report	x	
Language	FORTRAN	
Equipment	IBM 360	

Validation/calibration: Based on APRAC-1A

Time resolution: 1 hour

Spatial resolution: Radial segments-22.5° out to 16 km from receptor point

V FREE UNIVERSITY OF BERLIN

Numerical Simulation of Temporal and Spatial Distributions of Urban Air Pollution Concentration. H. D. Fortak, Proc. of Symposium on Multiple-Source Urban Diffusion Models, Chapel Hill, N.C., APCO Pub. No. AP-86, 1970.

A. Author's Abstract

A multiple-source diffusion model for the simulation and prediction of long-term (climatological) ground-level sulfur dioxide concentrations in urban areas is described. The computer input consists of data from an emission source inventory together with statistics on relevant diffusion parameters.

Because of the capacity of available computers, only a limited number of the largest emission sources (approximately 150) can be treated individually. Smaller industrial emission sources are treated as residential sources. These are represented by a large number of stacks (about 150) of the same dimensions, distributed over areas of 1 square kilometer, for which the mean area emissions have been estimated.

The meteorological input consists of data on wind direction, windspeed, and Pasquill-Turner stability classes. These parameters are assumed to be spatially homogeneous throughout the metropolitan area. Low-level emissions (residential) are correlated with low-level windspeeds and Pasquill-Gifford diffusion parameters, whereas high-level emissions (industrial) are correlated with extrapolated windspeeds and Brookhaven diffusion parameters. The program also uses corresponding statistics for urban boundary layer depths and values for parameters affecting absorption at the earth's surface.

The diffusion model used is basically Gaussian. It is modified, however, such that turbulent diffusion is restricted exclusively to the

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depth of the urban boundary layer. This is true for all sources having effective emission heights less than the height of the upper limit of the boundary layer. The rate of decay of sulfur dioxide is taken into account, as well as the experimentally determined absorption at the earth's surface.

The model calculates fields of steady-state ground-level concentrations that correspond to a given spatial distribution of emission sources and to any possible combination of relevant meteorological diffusion parameters. Knowledge of frequency distributions of these meteorological diffusion parameters permits the derivation of frequency distributions of ground-level concentrations for any location within or outside of the metropolitan area. The computerized experiments simulate frequency distributions of ground-level concentrations for a great number of regularly arranged grid points (up to 2500 with a mesh size of 500 by 500 meters) and for a variety of time periods (months, heating period, seasons, year, etc.). The frequency distributions are characterized by a limited number of parameters (mean, percentiles, etc.). Each parameter is plotted as a system of isograms on a map of the metropolitan area.

Experiments to validate the model were conducted during the heating period in 1967-68 at four continuously monitoring stations that had been installed at special locations within the limits of the metropolitan area of Bremen. During the sampling period, the assumption of a sufficiently homogeneous wind field was validated by wind measurements at the same locations. The calculated frequency distributions of half-hourly mean values of concentrations generally agreed fairly well with those derived from observed values. Comparison, however, shows that the model does not simulate ground-level concentration fields in the vicinity of industrialized areas very well, because uncontrollable low-level emissions from industrial plants could not be taken into account in the diffusion model.

B. Summary

Sources in the city of Bremen, Germany, are classified in three groups. First are individual stacks with emission rates greater than one kilogram of SO_2 per hour, which are treated as point sources. Records for these sources contain information as to output by volume, maximum emissions, and mean winter and summer emissions. Whenever possible, daily emission variation data and emissions for holidays were obtained.

The second source category includes individual stacks from small industries that contribute less than 0.02% each to the total emission rate. Since these sources contribute such a small amount to the total emissions, they are treated in the same manner as emissions from space heating.

Emissions from space heating are apportioned as area sources in a 500 × 500-meter grid. From the sulfur content of the fuels, the total fuel consumption and the total number of dwelling units, a mean emission rate of 8 g SO_2/hr per dwelling unit is obtained. This rate assumed the daily mean temperature remains constant throughout the heating period. To make emissions from space heating a function of time, a relationship between daily mean temperature and daily emissions is used in some cases. Multiplying 8 g/hr (or the corresponding temperature corrected value) by the number of dwelling units in each area gives the mean emission rate for that area. This is then divided by the number of individual stacks representing the area source.

C. Model Availability

A computer code for the emission inventory methodology is not presented.

VI GENERAL ELECTRIC COMPANY

Study of Air Pollution Aspects of Various Roadway Configurations; APTD-1146; New York City Dept. of Air Resources, EPA, FHWA, New York Division Office; Prepared by General Electric Company, 3198 Chestnut Street, Philadelphia, Pa., 1971.

A. Author's Abstract

This experimental study was undertaken to (1) ascertain the current air quality in the immediate vicinity of various urban roadway configurations; (2) determine how the selected urban roadway configurations aid or hinder the diffusion of the pollutants emitted by urban traffic; and (3) develop mathematical relationships between traffic, traffic speed, pollutant concentration, meteorological parameters and roadway configuration. It is possible to assess the impact of the 1970 Clean Air Act by future monitoring programs which determine the extent to which the clean air goals are achieved. It is possible to identify those areas in and around a given configuration that do not meet the National Air Quality Standards under certain meteorological and traffic conditions. It is possible for urban and transportation planners to compute in advance the pollution anticipated for a proposed roadway design in order to insure that dwellings adjacent to the proposed design will not be exposed to pollutant concentrations in excess of the National Air Quality Standards.

B. Summary

One section of the report presents nomographs which provide highway designers with gross estimates of the CO concentration to be expected for various roadway configurations. Figure A presents representative relationships of CO concentration versus traffic flow rate for one of

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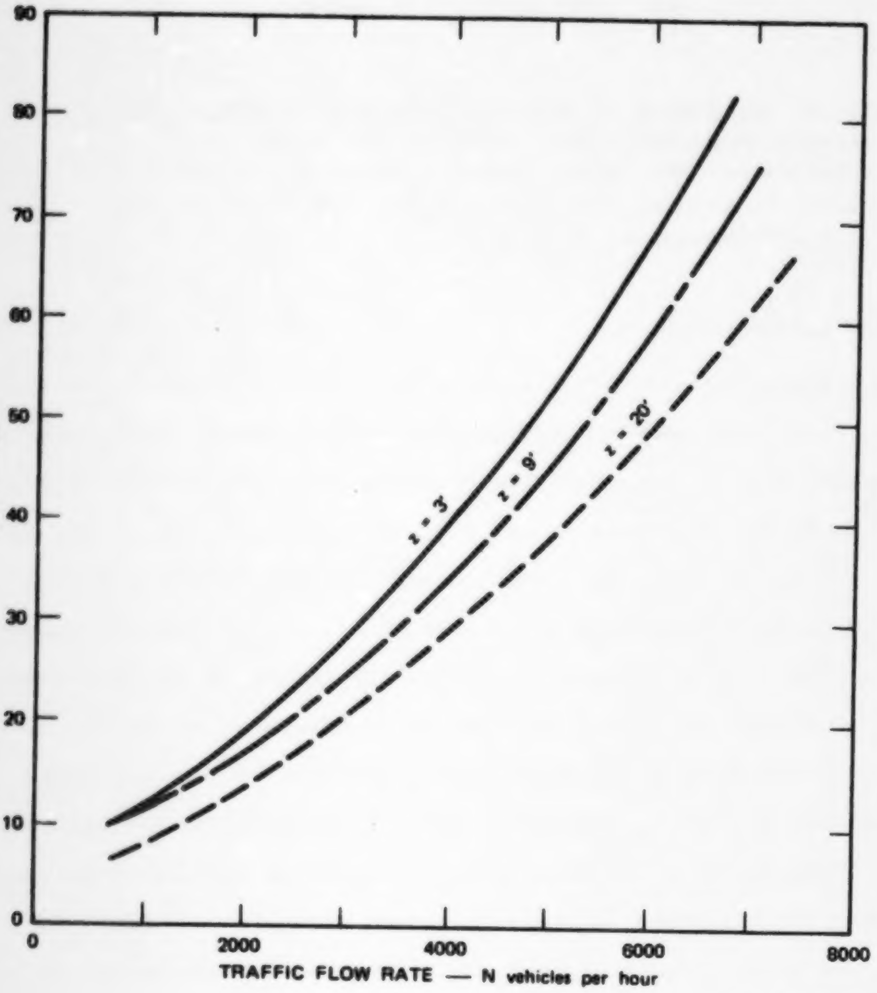

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FIGURE B-3 PROFILE OF CARBON MONOXIDE VERSUS TRAFFIC FLOW RATE AT FDR DRIVE the ten sites monitored during this study. The CO values shown in the curves are those of the vertical plane of probes reflecting the maximum values. The traffic values shown are those of the total traffic involved.

Regression and correlation analyses were performed to determine whether the relationship between environmental variables and carbon monoxide and hydrocarbon concentrations could be predicted mathematically.

The resultant simple correlation coefficients and multiple correlation coefficient, R, show large variations. It must be concluded, therefore, that the postulated regression equation does not adequately describe the effects of the wind parameters on the carbon monoxide and hydrocarbon concentrations.

It is assumed that any given roadway can be divided into independent line sources and each probe located at the roadway measures the concentration from its immediate line source plus the concentration emanating from the other $(x-1)$ line sources. Furthermore, it is assumed that the concentration decreases exponentially with distance from each probe location.

The model was further generalized by defining the vehicular pollution factor, ϕ, by dividing the unperturbed concentration, CO_2, by the traffic flow rate in the immediate vicinity of the probe location.

The vehicular pollution factor, ϕ,

$$\phi = \frac{CO_x}{\dot{N}} \tag{1}$$

For eight of the configurations evaluated, it was found that ϕ shows a strong linear relation with traffic speed (correlation of 0.81) as shown by Figure B. The viaduct site exhibited pronounced meteorological effects which resulted in the two lower points to the extreme left in the figure. The low velocity points in the lower right hand is data collected

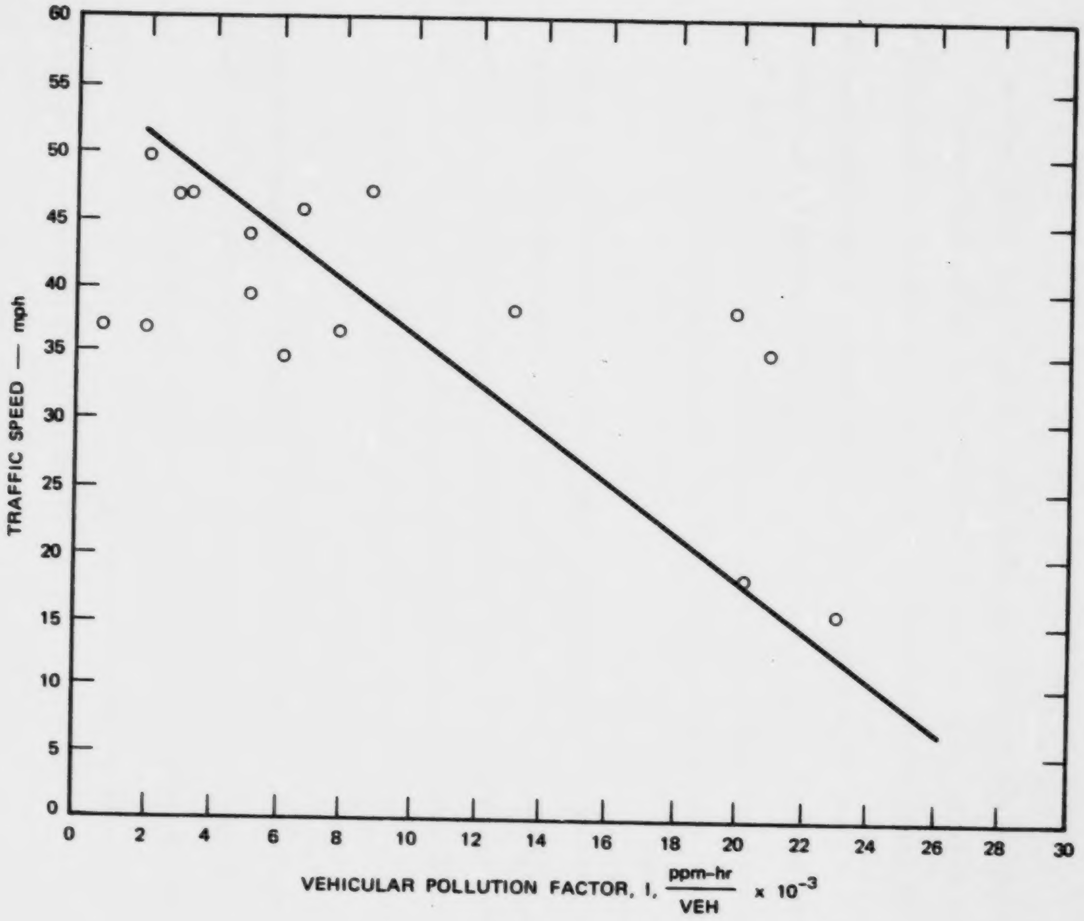

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FIGURE B-4 RELATIONSHIP BETWEEN VEHICULAR POLLUTION FACTORS TAKEN AT EXHAUST PLANE TRAFFIC SPEED in a city street. Data from the tunnel sites was not included in Figure B.

The linear relation between ϕ and traffic speed was found to be:

$$\phi_i = [-0.51\ (T_i) + 26.9] = 10^{-3} \qquad (2)$$

for T: 15 mph $\leq$ T $\leq$ 49 mph

ϕ_i = Apparent emission factor $\frac{\text{(PPM-Hr)}}{\text{veh}}$

T_i = Average Traffic Speed in lane i

It is seen from Equation (2) that traffic speed is the predominant factor and that the ranking of the sites must be based upon traffic speed, as well as site configuration. Stated in other terms, the line source strength decreases with increasing automobile speed due to the measure in vehicular induced turbulence and engine efficiency.

EMISSION MODELS CHECKLIST

Input Data Requirements

	Within Program	User Supplies	From AP-42	Proxies/Comments
Vehicle Emission Factors				
-By model year		NP		Experimentally measured at roadside for CO
-By size class	x	NP		
-By power plant		NP		
-Deterioration factor		NP		
Vehicle Operating Modes				
-Hot/cold start		NP		
-Route average		NP		
-Link average		NP		Average speed at point of measurement
-Mode-by-mode		NP	NP	
Traffic Features				
-Vehicle mix		NP		Hourly traffic count at point of measurement.
-Engine operating time		NP	NP	
-Vehicle miles traveled		NP	NP	
-Fuel consumed		NP	NP	
Spatial Distribution				
-Links			NP	
-Grinds			NP	
-Area		x	NP	Determined for area bounded by roadway configuration

---

NP = No provision

Output Available

Pollutants		
-CO	Yes	
-HC	No	(Could not obtain statistically "good" results)
-NO_x	No	
-Particulates	No	

Availability of Program Documentation

	Yes	No
Included in report		x
Referenced in report		x
Language	NP	
Equipment	NP	

Validation/calibration: Calibrated/validated for 10 different roadway configurations in NY Metropolitan area

Time resolution: 1 hour

Spatial resolution: Area occupied by roadway configuration

VII GENERAL RESEARCH CORPORATION

Evaluation of a Diffusion Model for Photochemical Smog Simulation. A. Q. Eschenroeder, J. R. Martinez, and R. A. Nordsieck, Final Report, General Research Corporation, prepared for Environmental Protection Agency, Contract No. 68-02-0336, October, 1972.

A. Author's Abstract

Extensive improvements have characterized this evaluation of the GRC Photochemical/Diffusion model. Despite the limitations of smog chamber experimental data, they have served an essential purpose toward updating the kinetics portion of the model. Consistency of rates and reactivities is now achievable using recently measured coefficients for a wide variety of systems. Model methodology revisions have enhanced the realism of the advective and diffusive descriptions. Previous assumptions regarding transverse (cross-streamline) horizontal diffusion have been confirmed by an exhaustive series of parametric tests. Photochemical/diffusion validations were successful for trajectories occurring during four days of the 1969 smog season in Los Angeles. Our measure of success is concentration-history fidelity with a minimum of adjustments of diffusion parameters. (Chemical coefficients were scaled from the smog chamber studies and held fixed for the simulations carried out to date.) Future directions for air pollution model development are discussed in detail in an appendix as information supporting the experimental recommendations.

B. Summary

General Research Corporation's diffusion model uses hourly emissions of carbon monoxide, ozone, hydrocarbons, nitrogen dioxide and nitric oxide

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from both fixed and moving sources on a 2-mile interval grid to predict pollutant concentrations. The emissions inventory used is that compiled by Systems Applications, Inc., (see Review No. XXII).

VIII GEOMET

Validation and Sensitivity Analysis of the Gaussian Plume Multiple-Source Urban Diffusion Model. R. C. Koch and S. D. Thayer, Geomet, Inc., Final Report, Contract No. CPA 70-94, prepared for Environmental Protection Agency, November, 1971.

A. Author's Abstract

This report, submitted by GEOMET to the National Environmental Research Center, presents the analysis and results of a program of validation and sensitivity analysis of the steady-state Gaussian plume-type of urban diffusion model.

The report develops a careful definition of the fundamental short-term steady-state model and its various modes of implementation, in terms of emission and environmental input parameters, and of calculational modes. A set of computer programs developed especially for validation and sensitivity study purposes is described.

The validation study consists of a variety of comparisons of short-term and long-term concentration predictions from the model, with comparable measured SO_2 concentrations covering three months of 2-hour values at ten locations in St. Louis, and one month of 1-hour values at eight locations in Chicago. The predictions use hourly estimates of meteorological and emission parameters. The atmospheric stability is estimated from hourly weather observations from an adjacent airport using the McElroy-Pooler diffusion parameters based on Turner's definitions of stability categories. The mixing layer ceiling is estimated from radiosonde observations taken twice daily from remote locations (100 to 200 miles away). The wind speed and direction are

hourly averages of several continuous records. The emission rates of the largest sources are identified and located individually. For other sources a mean emission rate per unit area is estimated for a square gridwork of points with a one-mile spacing between adjacent points. Each emission rate is related to hourly estimates of space heating and other operating requirements. No "calibration" or other adjustment of the inputs or output concentrations is employed anywhere in the analysis.

Individual short-term model results (1- to 2-hour periods) show large deviations from the observed concentrations, but the frequency distributions of calculated short-term concentrations over a month or a season compare quite well with the comparable frequency distributions of observed concentrations. No single factor could be found which accounts for a significant fraction of the individual deviations. Predicted long-term concentrations show consistently good agreement with observations, as contrasted with the significant overestimation usually found in other model implementations.

A technique is proposed for calculating the long-term estimates which obviates the need to calculate every short-term concentration in the period. A sampling process is used in which a statistically selected set of as few as five to ten percent of the short-term periods is employed, and the representativeness of the distribution is maintained.

In the sensitivity analysis, the insensitivity of the model concentrations to the parameters of wind speed profile parameter value, and the distribution of area source emission heights, is demonstrated. Quantitative description is given of the sensitivity of the model to the following parameters: changes in spatial variability in emissions, vertical diffusion parameter, pollutant half-life, wind speed, mixing ceiling, wind direction, and downwind variation in emission rates.

Finally, recommendations are made on implementation and use of the model described herein, and for further study in special problem areas highlighted by the study.

B. Summary

The GEOMET multiple-source diffusion model designates individual sources with emission rates significantly higher than the average rate as point sources, e.g., power plants, large industrial plants, and large commercial and municipal emitters. For the remaining emitters (area sources such as residential homes, high-rise apartments, and various smaller commercial and industrial establishments), it is assumed that an average emission rate is representative of a small region. Hourly estimates of SO_2 point and area source emission rates are required. Two methods of parameterizing temporal and spatial variations of these rates have been used in this study, one for the St. Louis emissions data and one for the Chicago data.

1. Treatment of St. Louis Emission Data

The following algorithms for estimating SO_2 emissions as a function of time of day, day of week, location, and temperature were adapted from methods developed by D. B. Turner.*

a. Area Sources

Area source emissions were divided into 5000 × 5000-foot grid squares, and included data from residential, commercial, river vessel, automobile, railroad, backyard burning, and industrial sources. Turner suggests the following algorithm for area sources:

---

* Personal communication to GEOMET, Inc.

$$Q(t) = Q_r + q_r D_r(t) + Q_c F_c(t) + q_c D_c(t) + Q_v + Q_a F_a(t) + Q_w + Q_b$$

$$+ q_x D_c(t) + Q_p F_d(t) F_h(t)$$

$$D_r(t) = 65 - T(t) - \Delta_r(t)$$

$$D_c(t) = 65 - T(t) - \Delta_c(t)$$

where $Q(t)$ = SO_2 emission rate

Q_r = base residential SO_2 emission rate

q_r = residential heating SO_2 emission rate per degree

$T(t)$ = ambient air temperature

$\Delta_r(t)$ = residential temperature correction factor

$\Delta_c(t)$ = commercial temperature correction factor

Q_c = base commercial SO_2 emission rate

$F_c(t)$ = commercial diurnal variation factor

q_c = commercial heating SO_2 emission rate per degree

Q_v = river vessel SO_2 emission rate

Q_a = base automotive SO_2 emission rate

$F_a(t)$ = automotive diurnal variation factor

Q_w = railroad SO_2 emission rate

Q_b = backyard burning SO_2 emission rate

q_x = industrial heating SO_2 emission rate per degree

Q_p = base industrial process emission rate

$F_d(t)$ = industrial day of week variation factor

$F_h(t)$ = industrial diurnal variation factor

Introducing subscript notation, let i,j appear on parameters that vary from one area source to another, let k denote fuel type, a denote annual or national average, and ℓ refer to the hourly period. Then

$$\left(q_r\right)_{ij} = \frac{H_a R_{ij}}{D_a R_a} \sum_{k=1}^{K} \frac{S_k \left(N_k\right)_{ij}}{E_k H_k}$$

where H_a = average annual U.S. household space heating energy requirement

D_a = average annual U.S. degree days

R_a = average number of rooms per U.S. household

R_{ij} = average number of rooms per dwelling unit in grid square (i, j)

S_k = SO_2 emitted per unit fuel k

E_k = heating efficiency of fuel k

H_k = heat content of fuel k

$\left(N_k\right)_{ij}$ = number of residential dwelling units using fuel k in grid square (i,j)

$$\left(Q_r\right)_{ij} = \frac{F_s}{1-F_s} \left(q_r\right)_{ij} \overline{D_w}$$

K = number of fuels

where F_s = summer day fuel consumption as fraction of average winter day

$\overline{D_w}$ = average winter degree day

$$\left(Q_c\right)_{ij} = \frac{1}{\Delta t_s} \sum_{k=1}^{K} S_k \sum_{\ell=1}^{C_{ij}} \left(F_s\right)_{k\ell} W_{k\ell}$$

where Δt_s = duration of season

C_{ij} = number of commercial sources in grid square (i,j)

$W_{k\ell}$ = annual quantity of fuel k used by ℓth source

$(F_s)_{k\ell}$ = fraction of annual quantity of fuel k used by ℓth source in summer season

S_k = SO_2 emitted per unit of fuel k

$$(q_c)_{ij} = \frac{1}{D_w}\left\{ \frac{1}{\Delta t_s}\left[\sum_{k=1}^{K} S_k \sum_{\ell=1}^{C_{ij}} (F_w)_{k\ell} W_{k\ell}\right] - (Q_c)_{ij} \right\}$$

where D_w = winter season degree days

$(F_w)_{k\ell}$ = fraction of annual quantity of fuel k used by ℓth source in winter season

$$(q_x)_{ij} = \frac{1}{D_w} \sum_{k=1}^{K} S_k \sum_{\ell=1}^{I_{ij}} (F_w)_{k\ell} W_{k\ell}$$

where I_{ij} = number of industrial sources in grid square (i,j)

Substituting, the original algorithm becomes

$$Q_{ij}(t) = \left[\frac{F_s \overline{D}_w}{1-F_s} + 65-T(t)\right] - \Delta_r(t)\ \frac{H_a R_{ij}}{D_a R_a}\left[\sum_{k=1}^{K} \frac{S_k (N_k)_{ij}}{E_k H_k}\right]$$

$$+ \left[\frac{F_c(t)}{\Delta t_s} - \frac{65-T(t) - \Delta_c(t)}{D_w}\right]\left[\sum_{k=1}^{K} S_k \sum_{\ell=1}^{C_{ij}} (F_s)_{k\ell} W_{k\ell}\right]$$

$$+ \frac{65-T(t) - \Delta_c(t)}{D_w}\left[\sum_{k=1}^{K} S_k \sum_{\ell=1}^{C_{ij}} (F_w)_{k\ell} W_{k\ell}\right]$$

$$+ Q_v + Q_a F_a(t) + Q_w$$

$$+ Q_b + \frac{65-T(t) - \Delta_c(t)}{D_w}\left[\sum_{k=1}^{K} S_k \sum_{\ell=1}^{I_{ij}} (F_w)_{k\ell} W_{k\ell}\right]$$

$$+ F_d(t)F_h(t) \sum_{\ell=1}^{I_{ij}} (Q_p)_\ell$$

Effective emission heights for area sources are determined primarily on the basis of prevalent building heights in the area.

b. Point Sources

Industrial Sources. Sulfur dioxide emissions from industrial sources are comprised of emissions from process and space heating fuel consumption. Process fuel emissions are estimated by the product of the peak process emission rate and factors related to the temporal variation of emissions. Space heating emissions are determined in terms of degree day response. The SO_2 emission rate, $Q(t)$, is expressed by

$$Q(t) = Q_p F_d(t) F_h(t) + q_x D_c(t)$$

where Q_p = peak process SO_2 emission rate

$F_d(t)$ = fraction of peak for day of week

$F_h(t)$ = fraction of peak for hour of day

q_x = heating fuel SO_2 emission rate per degree

$D_c(t) = 65 - [T(t) + \Delta_c(t)]$

$T(t)$ = ambient air temperature

$\Delta_c(t)$ = commercial temperature correction factor

The quantities Q_p, $F_d(t)$ and $F_h(t)$ are obtained from questionnaires containing plant operation statistics. According to season, q_x is

$$q_x = \frac{1}{D_a} \sum_{j=1}^{n} W_j S_j$$

or

$$q_x = \frac{1}{D_w} \sum_{j=1}^{n} \left(F_w\right)_j W_j S_j$$

where W_j = annual quantity of fuel j used

S_j = SO_2 emitted per unit fuel j

D_a = annual number of degree days

D_w = winter season degree days

$\left(F_w\right)_j$ = fraction of annual quantity of fuel j used in winter season

The SO_2 emission rate equation then becomes

$$Q(t) = Q_p F_d(t) F_h(t) + [65 - T(t) - \Delta_c(t)] \frac{1}{D_a} \sum_{j=1}^{n} W_j S_j$$

In addition to emission rate parameters, data inputs include location coordinates of the source, physical stack height and the plume rise, wind-speed product.

Power Plant Sources. According to the available data, one of two methods of estimating power plant emission is used.

For some plants hourly power outputs were available. The information included graphs of fuel weight flow rate, stack temperature, and stack exit gas volume flow rate as functions of power output. A linear relationship was found between fuel flow rates and power output:

$$F = A_1 + A_2 L$$

where F = fuel weight flow rate

L = power output

A_1, A_2 = empirical parameters

Emission rates are

$$Q = FE \frac{S}{100},$$

where $Q = SO_2$ emission rate

F = fuel flow rate

$E = SO_2$ emission factor

S = percent sulfur content of fuel

Stack temperature and volume flow rate are also linearly related to output, but it was found necessary to divide the range of power outputs from zero to a peak value into three equal parts and to use a linear approximation over each part or class of the range. This gives

$$T_s = T_\ell + \frac{\left(L-L_\ell\right)}{L_p/3}\left(T_u - T_\ell\right)$$

where T_s = stack temperature

L = power output

L_ℓ = lower limit of power output class

L_p = peak power output

T_ℓ = stack temperature for power load of L_ℓ

T_u = stack temperature for power load of $L_\ell + 1/3\ L_p$

and

$$V_s = V_\ell + \frac{L - L_\ell}{L_p/3}\left(V_u - V_\ell\right)$$

where V_s = stack gas volume flow rate

V_ℓ = stack gas volume flow rate for power load of L_ℓ

V_u = stack gas volume flow rate for power load of $L_\ell + 1/3\ L_p$

For another plant, estimates were made for each two-hour period of the day of average emission rates, wind speed and plume rise product. These estimates were derived by government personnel based on discussions with the plant operator, and are assumed representative of all days in the data period.

2. Treatment of Chicago Emission Data

The algorithms employed by GEOMET to obtain hourly SO_2 emission rates from the Chicago emission data were those developed by Argonne National Laboratory and described previously in Section II of this appendix. The area source grid consists of one mile squares. Additions to the algorithms include Turner's temperature correction factor in the residential and commercial area source treatments and the following equation for describing heat emission rates for the three classes of additional point sources:

$$H_e = 0.15\,\frac{240\,Q}{\frac{S}{100}\;3680\,N}$$

where H_e = heat emission rate

Q = SO_2 emission rate

S = percent sulfur content of fuel

N = number of stacks

3. Model Sensitivity

Sensitivity to the vertical distribution of area source emissions was investigated. It was concluded, for the cases tested, that in general the differences resulting from the use of various vertical distributions were negligible.

To study model sensitivity to diurnal variation in emission rates, the factors(represented by algorithms) which affect emission rate estimations were analyzed. The inputs to the algorithms are temperature, electric power load at generating stations, and hour of the day, but errors associated with the measurement of these inputs are small. Therefore, the assumptions made in formulation of these algorithms were investigated.

In the emissions model, annual emission rates act as scaling factors for diurnal variations; an error in one of these estimates creates systematic error in model predictions. However, the authors feel that if concentrations are considered at a number of widely dispersed locations, the errors tend to cancel each other.

Sulfur dioxide emissions are characterized as arising from three classes of operations: (1) electric power generation, (2) industrial processing and (3) space heating. Hourly power plant emissions are estimated by means of linear relationships with hourly electric power load of individual generating units. Error in this regard is small, but uncertainty would be increased for proposed power plants where hourly loads would need to be predicted.

Diurnal emissions from industrial processing are allocated on the basis of utilization factors concerning day of the week, hour of the day, etc. Variations between actual and estimated emissions may be considerable, since industrial operations must respond to fluctuations in demand and breakdowns in equipment. The authors state that errors in emission rate estimated in the immediate vicinity of individual sources result, but a random distribution of these over an urban area tend to balance.

Algorithms for emissions from space heating operations contain correction factors such as Turner's temperature correction factor and Argonne's "janitor function." It was felt that random errors associated with individual sources of these types are probably small, and a more serious type of error is associated with the assumputions in the algorithms of no time lag between outside temperature change and fuel consumption. This type of error is critical to short-term model sensitivity, sometimes resulting in an emission error of a factor of 2; it is not important in calculating long-term concentrations.

Systematic errors due to unseasonable temperatures can result when thermostats are controlled only partially by temperature, since the algorithm will immediately respond to the temperature change. In these cases, the emission rate error will persist for the duration of the unseasonable weather. The resulting concentration error will be minimal over the long-term, but short-term concentration error will be directly proportional to the emission error. A careful study of the magnitude and duration of heating emissions is required to determine the nature of heating system response to rapid and extreme temperature fluctuations.

C. Model Availability

Computer program listings of the emissions treatments for both Chicago and St. Louis data appear in the GEOMET report.

IX IBM

The IBM Air Quality Diffusion Model with an Application to New York City. L. J. Shieh, P. K. Halpern, B. A. Clemens, H. H. Wang, and F. F. Abraham, IBM Corp., Palo Alto Scientific Center, Report No. G320-3290, June, 1971.

A. Author's Abstract

An experimental multisource air pollution diffusion model based on the Gaussian plume formulation is described. The model is capable of incorporating point and area sources, time and space dependence of source strengths, and time and space dependence of meteorological variables. Numerical experiments sumulating the SO_2 concentration distribution for New York City are presented for January 11, 1971. The numerical results agree favorably with experimental measurements.

B. Summary

The IBM diffusion model requires 2-hourly SO_2 emissions data in order to predict the average ground level concentrations for a 2-hour interval. The emissions treatment recognizes individual point sources, which include power generation, municipal incinerators, manufacturing plants, industrial combustion, chemical and oil refinery and mineral smelting, large hospitals, etc; and area sources, which account for commercial and domestic space and hot water heating.

1. Treatment of Area Sources

The grid square size for area sources is variable, allowing for specification of different grids for urban, sub-urban, and rural areas. These specifications are based on receptor locations relative to the sources and the distribution of source strengths. Computations were made using a 1.0 × 1.0-mile square grid in the urban area, 2.0 × 2.0 in the sub-urban area, and 4.0 × 4.0 in the rural area. Necessary inputs include the number of different area source sizes used and the number of area source grids in each area source size; the model groups source grids (for any grid size) in a rectangular region, thus also requiring as input the number of rectangular regions for the entire source grid; and, for each region, the x,y coordinates denoting the limits of the region and the size of the source grid for that region.

A source emission height for each area source size must be input to the model, and it is taken as the average building height within the area source grid.

Total annual SO_2 emissions are first broken down into daily, then 2-hourly emissions. One method used to generate daily patterns was to relate daily emissions to the average daily temperature, where

$$Q_{daily} = \gamma_1 \frac{Q_{annual}}{365} + \gamma_2 \frac{Q_{annual}}{TDD} \text{ (DD)}$$

and Q_{daily} = daily total SO_2 output

Q_{annual} = annual total SO_2 output

DD = degree days = 65 - daily mean temperature in °F if the latter is 65°F or less; otherwise, it is zero

TDD = annual total degree days

γ_1 = fraction of sources due to hot water heating

γ_2 = fraction of sources due to space heating

and $\gamma_1 + \gamma_2 = 1$

An alternate approach divides the calendar year into three seasons and allocates fractions of the annual source emissions to each season. Let α_1, α_2 and α_3 represent these fractions. The seasonal emissions may be written as

$$Q_{\text{season 1}} = \alpha_1 Q_{\text{annual}}$$

where $\alpha_1 + \alpha_2 + \alpha_3 = 1$

Daily emissions are found by dividing by the number of days in the season in question. Estimates of daily emissions using this method are not as precise as those calculated by the former method. To reduce daily SO_2 output to 2-hourly source emissions, statistically derived coefficients representing diurnal variations of emissions as a function of ambient temperature are introduced. It is assumed that for each 10°F interval of daily mean temperature a typical diurnal emission pattern exists, from which these coefficients can be derived. Two-hour source emissions are calculated with the expression:

$$\sum_{i=1}^{12} Q\left(2 \text{ hour}_i\right) = \sum_{i=1}^{12} \beta_i Q_{\text{daily}}$$

where β_i (i=1, 12) equals the fraction of daily output at a particular 2-hour interval. Values of β_i are given in the table.

Small point sources are included with the area source emissions if certain criteria are satisfied: (1) the total annual emissions are less than one-tenth of the total annual emissions of the associated area source; (2) the stack height of the point source is within 20 m of the associated area source emission height; and (3) the point source has no appreciable plume rise. All other point sources are considered individually.

2. Treatment of Point Sources

The model requires bi-hourly emissions data from point sources, and if measured data are not available, the following simulation technique

β_1*

Temperature Range	Local Time											
	00-0200	02-0400	04-0600	06-0800	08-1000	10-1200	12-1400	14-1600	16-1800	18-2000	20-2200	22-0000
≥ 60°F	5.0	3.0	7.0	10.0	10.0	10.0	9.0	9.0	10.0	10.0	10.0	7.0
50-59°	3.0	3.0	11.0	14.0	12.0	9.0	7.0	7.0	9.0	10.0	9.0	6.0
40-49°	3.0	3.0	9.0	10.0	11.0	10.0	10.0	9.0	10.0	10.0	10.0	5.0
30-39°	3.0	3.0	9.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	9.0	6.0
≤ 29°	5.0	6.0	.0	10.0	9.0	9.0	9.0	8.0	9.0	10.0	9.0	7.0

---

* These coefficients were determined using limited data obtained in New York City during 1966. IBM Corporation stresses that these data should be used with extreme care when attempting application to other cities during other years, and state that they are not responsible for their accuracy.

(i.e., emission model) is suggested by the authors. Point sources are classified according to industry, and operational modes for each industry are established. Patterns for daily output will vary according to mode of operation; that is, operation on weekdays versus weekends, seasonal trends, shift factors, etc. Several patterns for a particular industry are distinquished, and diurnal emissions are obtained through the application of the various factors derived from the patterns appropriate to the mode of operation under consideration.

C. Model Availability

The computer program for the IBM model is considered experimental and is not available outside IBM.

X IBM

Source Emissions and the Vertically Integrated Mass Flux of Sulfur Dioxide Across the New York City Area.

P. Halpern, C. Simon, and L. Randall, Journal of Applied Meteorology, 1971.

A. Author's Abstract

Sulfur dioxide concentrations (in ambient air), obtained from helicopter soundings and traverses, together with wind data from pibals, were used in a kinematic box model to determine hourly average three-dimensional fluxes of SO_2 for the New York City area. Continuous dry-bulb temperature and pressure height records were obtained concurrently and utilized in the analysis and interpretation of the flux data.

The SO_2 fluxes were compared to degree-day-dependent emissions from residential, industrial and utility sources. Results indicate that the vertical structure of the fluxes is related to diurnal variations of the temperature lapse rates. Furthermore, the emission rates determined from the measurement of flux in 13 tests agree with those derived from the New York City sulfur dioxide emission inventory within limits which have been considered acceptable for use in air pollution modeling.

B. Summary

1. Treatment of Emissions

The emissions treatment described by Halpern et al., considers hourly SO_2 emissions from residential, utility, and industrial sources. Hourly values of power plant emissions were obtained from the utility companies. Hourly manufacturing and industrial emissions are estimated by uniformly distributing annual emissions data over an 8-hour day,

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5-day week, and 50-week year. Daily residential emissions are obtained in the manner described in the IBM model summary previously given. Diurnal variations in residential rates are estimated using data on duration of hourly operation times for apartment house boilers using fuel oil. Total boiler operating time for each day is correlated with degree day values:

$$t = 17.2TT + 192.0$$

where t equals the total operation time of the boiler in minutes and TT represents the degree days. Since space-heating boilers receive fuel oil at a constant rate when operating, knowledge of t and the fuel sulfur content is sufficient to describe the hourly SO_2 emission rate.

2. Model Validation

Sulfur dioxide fluxes are calculated from concentration measurements taken by a helicopter and using wind measurements obtained from pibal and radiosonde soundings. A kinematic box model based on conservation of mass is used to verify the hourly emission rates and to demonstrate a mass balance of SO_2.

For thirteen test cases, the vertically integrated SO_2 flux was greater than the flux estimated from the emissions inventory. The average value of the ratio of source emissions flux to the vertically integrated flux was 0.74 for tests during May and 0.83 for tests in November. The authors state that this indicates that the source emission estimates were more responsive to the degree-days dependence in the colder November tests than in the warmer May tests. The average value for the ratio for all tests was 0.78.

The mass balance of SO_2 has been verified by comparing calculated SO_2 flux to source emission data.

C. Model Availability

A computer program for the emission inventory methodology presented is not included in the paper.

XI METROPOLITAN WASHINGTON COUNCIL OF GOVERNMENTS

Estimating Auto Emissions of Alternative Transportation Systems; Office of the Assistant Secretary for Environment and Urban Systems, Washington, D. C. 20590; Prepared by S. D. Berweger and G. V. Wickstrom, Dept. of Transportation Planning, Metropolitan Washington Council of Governments, 1972.

A. Author's Abstract

This report discusses the development and application of a model which can estimate the relative magnitudes of carbon monoxide, hydrocarbons, and oxides of nitrogen automobile emissions for alternative regional transportation systems.

The computation of auto emissions is accomplished by means of a computer program which accepts travel and facility data, together with assumed emission rates, and calculates speed and vehicle-miles of travel by type of facility by sub-area; applies the rates (for peak and off-peak travel speeds and volumes) and calculates the amount of emission by sub-area. Emission rates are a function of the speed of travel and the age distribution of vehicles in the year under study. A portion of the program logic is based on a model developed by the Tri-State Transportation Commission for estimating highway facility requirements, modified for the purpose of calculating auto emissions.

These findings are based on the emission factors supplied by E.P.A. If these factors are revised as a result of further research, it is quite possible that some of the results obtained would change. Revisions to the emission factors can be readily accommodated by the model developed in this study.

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B. Summary

The methodology makes use of vehicle trip forecasts, along with highway network information, to estimate future travel, the speeds at which this travel will occur, and the emission levels produced. The methodology does not require trip distribution and traffic assignment model procedures. It is aimed at providing a regional overview of the relative magnitude of the air pollution problem in an area. The methodology is not intended to provide air quality forecasts as no diffusion models have been used.

For each system, estimates of average daily and peak-hour emissions of carbon monoxide (CO), hydrocarbons (HC), and oxides of nitrogen (NO_x) were made and compared. Computer programs have been developed to do much of the work and are available.

The three-stage Auto Emissions Model developed in this study is shown in the figure. For each system tested, a trip generation sub-model is used to determine automobile vehicle trip origins, a travel description sub-model is utilized to convert those trips into travel characteristics and, finally, an emission sub-model is used to convert these travel parameters into estimates of pollutant emissions.

The emission sub-model utilizes average speeds, to determine the CO, HC, and NO_x emission rates, in pounds per vehicle mile, for each facility type. This rate is then multiplied by the VMT on each facility type to determine the total pollutants emitted for each of the sub-areas. This process is carried out for both peak-hour and daily conditions.

The emission factors used in this study were supplied by the E.P.A. CO and HC emissions per vehicle-mile of travel decrease with increasing speeds while emissions of nitrogen oxides are assumed to be constant for all speeds.

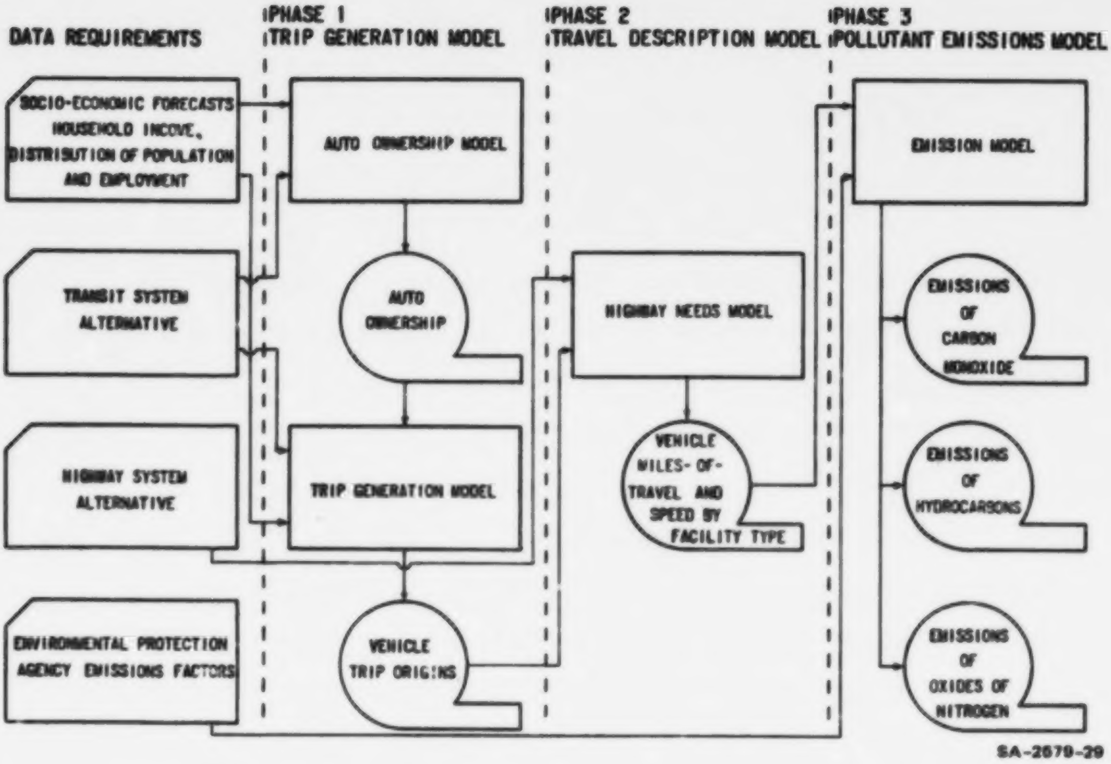
DATA REQUIREMENTS
PHASE 1
TRIP GENERATION MODEL
PHASE 2
TRAVEL DESCRIPTION MODEL
PHASE 3
POLLUTANT EMISSIONS MODEL
SOCIO-ECONOMIC FORECASTS HOUSEHOLD INCOME, DISTRIBUTION OF POPULATION AND EMPLOYMENT
AUTO OWNERSHIP MODEL
EMISSION MODEL
TRANSIT SYSTEM ALTERNATIVE
AUTO OWNERSHIP
HIGHWAY NEEDS MODEL
EMISSIONS OF CARBON MONOXIDE
HIGHWAY SYSTEM ALTERNATIVE
TRIP GENERATION MODEL
VEHICLE MILES-OF-TRAVEL AND SPEED BY FACILITY TYPE
EMISSIONS OF HYDROCARBONS
ENVIRONMENTAL PROTECTION AGENCY EMISSIONS FACTORS
VEHICLE TRIP ORIGINS
EMISSIONS OF OXIDES OF NITROGEN
SA-2679-29

FIGURE B-5 FLOW CHART OF AUTO EMISSIONS MODEL

There was concern over combining trip specific speed-emission factors with facility specific speeds. At the time the study was initiated, however, there were no data available to resolve this inconsistency.

The most important relationship used in the travel description sub-model is between vehicle-miles of travel (VMT) density, vehicle trip origin density, and expressway supply. In the Washington, D.C. area, the relationship was found to be the same as that found in the New York region, that is:

$$\text{VMT} = 64.3 \times \text{VTO}^{0.74} \times e^{(1.6 \times \text{FE/FO})}$$

where:

VMT = vehicle-miles of travel per square mile

VTO = vehicle trip origins per square mile

FE/FO = proportion of total roadway surface area made up by expressways

It was found that the expressway speed estimates calculated for the New York region were too high for use in the Washington area; therefore, the source deck was recompiled using a speed equation specifically calibrated for the Washington region.

To obtain an estimate of peak-hour speeds, the 24 hour VMT was factored to peak hour volumes per lane by facility type, using observed peak-to-daily and directional flow factors. The Technical Advisory Committee eventually decided that the EPA emission factors published in the EPA document, "Air Pollution Emission Factors"[*] were the best available for current use. These factors were modified somewhat by EPA to account for 1976 conditions and the fact that the age distribution of automobiles in the Metropolitan region was different (younger) than the national average.[**] This resulted in a slightly lower base emission rate for the region, but the proportional changes in rates for speed variations remained identical to that published.

Preliminary data from a current five-car study in California indicates that the impact of control devices might well be to flatten out the CO and HC curves, that is, emission rates may not decrease as rapidly for a given speed increase as they did under the old curves.

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[*] M. J. McGraw, and R. L. Duprey, "Compilation of Air Pollutant Emission Factors" (Preliminary Document), Environmental Protection Agency, Research Triange Park, N. C., April, 1971.

[**] "Motor Vehicle Emission Factors for Metropolitan Washington, D.C.," Environmental Protection Agency, Office of Air Programs Memo, November 4, 1971.

EMISSION MODELS CHECKLIST

Input Data Requirements

	Within Program	User Supplies	From AP-42	Proxies/Comments
Vehicle Emission Factors				
-By model year		x	x	
-By size class			NP	
-By power plant			NP	
-Deterioration factor			NP	
Vehicle Operating Modes				
-Hot/cold start	NP			Average speeds for each mode based on total VMT by mode
-Route average	NP			
-Link average	NP			
-Mode-by-mode	NP		NP	
Traffic Features				
-Vehicle mix	NP			
-Engine operating time	NP		NP	
-Vehicle miles traveled	x		NP	
-Fuel consumed	NP		NP	
Spatial Distribution				
-Links			NP	
-Grinds			NP	
-Area		x	NP	

NP = No provision

Output Available

Pollutants	
-CO	Yes
-HC	Yes
-NO_x	Yes
-Particulates	No

Availability of Program Documentation

	Yes	No
Included in report	x	
Referenced in report	x	
Language	Basic FORTRAN IV	
Equipment	IBM 360/30	

Validation/calibration: Calibrated/validated on emissions for Metropolitan Washington, D.C.

Time resolution: Peak/off-peak

Spatial resolution: Area specified by zonal configuration

XII NATIONAL AIR POLLUTION CONTROL ADMINISTRATION

St. Louis SO_2 Dispersion Model Study--Basic Data.
D. B. Turner and N. G. Edmisten, Unpublished report,
November, 1968.

A. Author's Abstract

This report contains descriptions of basic data for a three month period used with a research study formulating a dispersion model for the St. Louis Metropolitan Area. This includes emission information for sources of sulfur dioxide as well as methods of estimating emissions for each 2-hours for the three-month period, hourly meteorological data from routine and special instrumentation, and 24-hour sulfur dioxide concentrations for 40 locations and 2-hour concentrations for 10 locations.

B. Summary

This unpublished report outlines methods of computing the number of dwelling units per grid square and the population per grid square, from basic census data.

1. Estimation of the Number of Dwelling Units per Grid Square

When the census tracts are larger than a grid square, the procedure is to first calculate the total number of grid squares per census tract by dividing the number of acres in the tract by the number of acres in a grid square. The number of inhabited grid squares in the tract is estimated, deleting rivers, lakes, parks, etc. Weights are then assigned individually to the squares to adjust their dwelling unit density to that of the total census tract. The number of each type of heating unit (coal, gas, or oil) is estimated for an average grid square from census data.

Finally, the number of each type of heating unit per average grid square is multiplied by the assigned weights, giving the number of each type of unit in the grid square in question.

When the census tract is smaller than a grid square, the fraction of the total census tract in each grid square of which it is a part is estimated, and weights are assigned to each portion of the tract to compensate for nonresidential areas. The total number of each type of unit in the census tract is multiplied, individually, by the fraction of area and by the assigned weight. These products are summed for each of the census tracts within the grid square, yielding the number of each type of unit in the square.

2. Estimation of the Population per Grid Square

When the census tract is larger than a grid square, the total number of grid squares per census tract is calculated, and the number of inhabited grid squares in the tract is estimated. Weights are individually assigned to the squares to adjust their population density to that of the total census tract. By dividing the population of the total census tract by the number of grid squares per tract, the number of people per grid square is found. Finally, multiplying the average grid square population by the assigned weight gives the population of the grid square in question.

If the census tract is smaller than a square, the fraction of the total census tract in each grid square of which it is a part is estimated, and a weight is assigned to each portion of the tract to compensate for nonresidential areas. The total population of the tract is multiplied, individually, by both the fraction of area and the assigned weight, and the sum of these products, for each census tract within the grid square, equals the population of the square.

C. Model Availability

A computer code for the methodology presented is not included in the report.

XIII NATIONAL AIR POLLUTION CONTROL ADMINISTRATION

Emission Factors. A. H. Rose, Jr., W. D. Krostek, National Air Pollution Control Administration, June, 1969.

A. Author's Abstract

A method has been developed for the prediction of gaseous pollutants emitted into the national environment from on-the-road gasoline-powered vehicles. The method involved two quantities, the emissions emitted per mile traveled, and the total mileage traveled. Vehicular emissions were characterized by engine type and load under actual operating conditions. Five vehicle types and two use classes were used to define characteristic vehicular emissions. Vehicle types were automobile (auto), light duty truck (LDT), and three weight classes of heavy duty trucks (HDT). The two use classes were urban and rural.

The method allows comparison among the possible degrees of control, methods of control, and implementation dates. The method could be utilized on a regional rather than national basis, and could include particulates as well as gaseous pollutants.

B. Summary

1. Inputs

The method requires knowledge of: (1) the mean annual road emissions of a characteristic vehicle in mass per distance traveled, and (2) the total distance traveled during the calendar year by that portion of the total vehicular population characterized by the vehicle. Classification of vehicles was by use: urban or rural driving; and by general type: auto, LDT [GVW less than 6,000 lbs], HDT(II) [GVW of 6,000-10,000 lbs], HDT(III) [GVW of 10,000-19,500 lbs], HDT(IV) [GVW over 19,500 lbs]. Vehicles in a class were categorized by the model year (the model year is the calendar year the vehicle entered the population). This is basically

Preceding page blank

characterization of vehicular emissions by engine type, load, and age. Reference characteristic emissions were obtained for each of the vehicular types and use classifications. The deterioration factor used to account for vehicle age was considered to be solely a function of accumulated road mileage, thus accommodating changes among vehicles in driving usage. It was assumed that vehicular deterioration will not change and that the mileage distribution with age will also remain constant. HDT vehicles were assumed to deteriorate as automobiles, assuming that the increase in mileage traveled is offset by more durable construction.

Three gaseous pollutants were considered, hydrocarbons (based on a hydrogen/carbon ratio of 1.85 to 1.00), carbon monoxide, and nitrogen oxides (as NO_2). Emissions from evaporative sources and crankcase blowby were presumed to consist entirely of hydrocarbons.

Rural driving was characterized by hot start 45 mph (average route speed) operating conditions; urban driving, by cold start 25 mph (average) operating conditions. The relationships among the various operating conditions are themselves independent of mileage.

REFERENCE AUTOMOTIVE EMISSIONS[*]

Type	Value	1962	1963-1967	1968-1969	1970	1971-1974	1975-1990
NO_2 - exhaust	gm/mile	5.757	5.757	5.757	5.757	5.757	0.960
	ppm	1500	1500	1500	1500	1500	250
CO - exhaust	gm/mile	87.234	87.234	35.103	23.000	23.000	11.500
	%	3.7	3.7	1.5	1.0	1.0	0.5
HC - exhaust	gm/mile	5.678	5.678	3.428	2.200	2.200	0.611
	ppm	456	456	275	176	176	49
HC - evaporative	gm/mile	2.767	2.767	2.767	2.767	0.490	0
HC - crankcase	gm/mile	3.151	0	0	0	0	0

[*] Concentration values are based on exhaust volume of 70.68 standard cubic feet/mile and pollutant densities of 16.33 gm/scf for hydrocarbon, 33.11 gm/sfc for carbon monoxide, and 54.30 gm/scf for nitrogen dioxide.

Emissions are for federal composite cycle.

2. Outputs

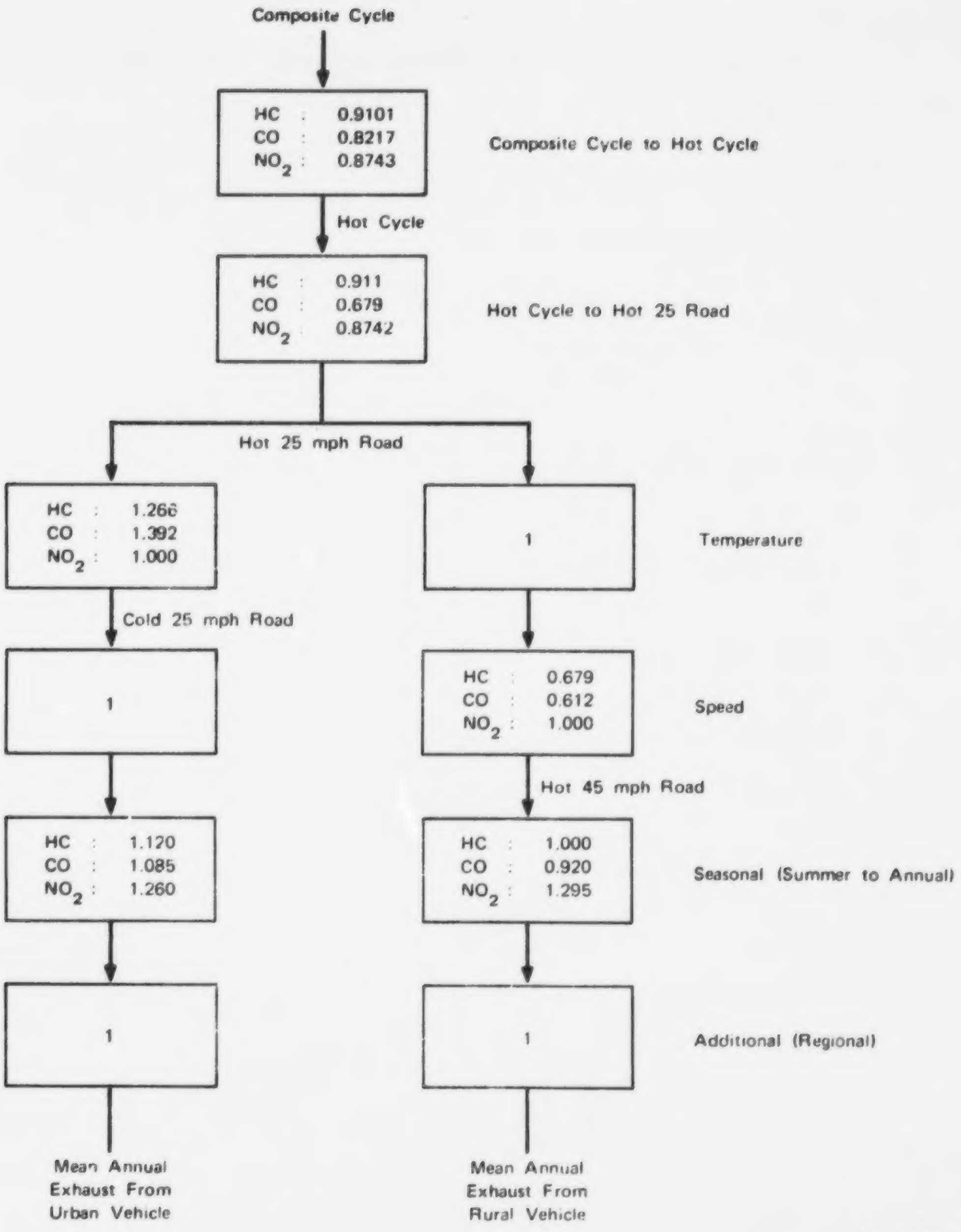
National or regional gaseous pollutants emitted from on-the-road gasoline powered vehicles.

3. Resolution

Annual national or regional.

4. Validation

None


Composite Cycle
HC : 0.9101
CO : 0.8217
NO_2 : 0.8743
Composite Cycle to Hot Cycle
Hot Cycle
HC : 0.911
CO : 0.679
NO_2 0.8742
Hot Cycle to Hot 25 Road
Hot 25 mph Road
HC : 1.266
CO : 1.392
NO_2 : 1.000
1
Temperature
Cold 25 mph Road
1
HC : 0.679
CO : 0.612
NO_2 : 1.000
Speed
Hot 45 mph Road
HC : 1.120
CO : 1.085
NO_2 : 1.260
HC : 1.000
CO : 0.920
NO_2 : 1.295
Seasonal (Summer to Annual)
1
1
Additional (Regional)
Mean Annual Exhaust From Urban Vehicle
Mean Annual Exhaust From Rural Vehicle

SA-2679-30

FIGURE B-6 EXHAUST EMISSION FLOW DIAGRAM

EMISSION MODELS CHECKLIST

Input Data Requirements

	Within Program	User Supplies	From AP-42	Proxies/Comments
Vehicle Emission Factors				
-By model year	x	x		Uses vehicle mix for year of interest in study
-By size class	x	x		
-By power plant	x	x		
-Deterioration factor	x	x		
Vehicle Operating Modes				
-Hot/cold start		NP		Average rural and urban routes
-Route average	x	NP		
-Link average		NP		
-Mode-by-mode		NP	NP	
Traffic Features				
-Vehicle mix		NP		
-Engine operating time		NP	NP	
-Vehicle miles traveled	x	x	NP	
-Fuel consumed		NP	NP	
Spatial Distribution				
-Links		NP	NP	
-Grinds		NP	NP	
-Area	x		NP	

NP = No provision

Output Available

Pollutants	
-CO	Yes
-HC	Yes
-NO_x	Yes
-Particulates	No

Availability of Program Documentation

	Yes	No
Included in report		x
Referenced in report		x
Language	NP	
Equipment	NP	

Validation/calibration: None

Time resolution: Annual

Spatial resolution: National or regional

XIV NORTHERN RESEARCH AND ENGINEERING

The Potential Impact of Aircraft Emissions Upon Air Quality.
M. Platt, R. C. Baker, E. K. Bastress, et al., Northern
Research and Engineering Corp., Cambridge, Mass., 02139,
Rept. APTD-1085, December 29, 1971.

A. Author's Abstract

Three categories of emissions were presented: aircraft operations, non-aircraft airport operations, and airport surroundings. In general, each of the sources in these categories can be accurately represented as either point, line, or area sources of time-dependent strength (i.e., emissions per unit time). However, to reduce the complexity of analysis in this study, each emission source is represented by one or more continuous point sources of constant strength over the time period being considered. Each point source is a specific location within the airport or its environs. The strength Q of a point source was evaluated as the total emissions E associated with the point during the time period, divided by the length T of the period.

B. Summary

1. Aircraft Operation

The modes of operation of a typical aircraft which were considered in this study have been established as: (1) approach, (2) landing, (3) taxi [after landing and before take-off], (4) idle and shutdown, (5) maintenance, (6) start-up and idle, (7) idle at runway, (8) take-off, (9) climb-out, and (10) fuel venting.

Operational modes

(4) idle and shutdown
(6) start-up and idle
(5) maintenance
(7) idle at runway

are characterized by pounds of pollutants per aircraft class. The total is calculated by using characteristic times periods for each mode for each aircraft class.

Operational modes

(3) taxi
(1) approach
(9) climb-out
(2) landing
(8) take-off

are characterized by pounds of pollutants per aircraft class. Distribution of traffic among runways, average taxi times, characteristics of the airport under study, and the times and positions along representative flight paths are used to calculate the amount and distribution of the pollutants.

Operational mode

(10) fuel venting

is characterized by total pounds of hydrocarbon per aircraft class and is associated with a point source at 600-meter altitude in take-off.

2. Automobile Travel

Automobile travel within the airport is characterized by a constant emission of pollutant per automobile per unit automobile travel. The total emissions due to automobile operation for a time period were calculated using:

a. Average travel per automobile within the airport

b. Fraction of automobiles entering the airport per passenger

c. Average number of passengers per aircraft

d. Aircraft activity data.

The first two items are considered characteristic of the airport, while the third item is considered characteristic of an aircraft class.

The total emissions were distributed along the airport roadway system, which in addition to highways, included roads within the parking areas. The distribution is accomplished by locating point sources at stations which divide each roadway into a number of equal segments. The emissions of each segment were equally divided between the two bounding stations. This resulted in the same type of distribution as would be obtained for trapezoidal integration of a uniform line source of emissions.

Service vehicle emissions were calculated in an approximate manner as 50% of automobile emissions. They are then included in the distribution of the automobile emissions.

3. Model Sensitivity

The mathematical model of airport emissions and the dispersion of those emissions used to predict pollutant concentrations involves two categories of physical parameters:

a. Meteorological parameters, which consist of atmospheric stability, wind speed, wind direction, mixing height, and for short-term calculations, wind persistence.

b. Source parameters, which consist of the strength and location of emission sources with respect to a receptor.

Parameters in the first category were the subject of a sensitivity analysis, with parameters in the second category investigated indirectly in the analysis of control techniques.

4. Accuracy of the Model

Airport emissions are modeled by a large number of continuous point sources of constant strength distributed throughout the airport. This results in two limitations on the validity of the model. First, the model is limited to time periods that are much larger than characteristic times of individual aircraft activity. Second, the model is limited to receptors that are not in close proximity to the emission sources. Since an airport has many emission sources which would be best represented as lines or areas, the assumption of point sources results in an important limitation of the model.

In providing a check of the results obtained using the model, a comparison was made with emissions and concentrations reported for Los Angeles International Airport. While the emissions for carbon monoxide are in excellent agreement, agreement for the other pollutants is poor. The aircraft emissions of particulates, nitrogen dioxide, and total hydrocarbons for Los Angeles International Airport are greater than those obtained using the model by factors ranging up to 6.7 for particulates. Since the activity data were similar for the two cases, the disagreement can be traced directly to the emission factors.

Concerning the other pollutants, it is significant that agreement is so good for carbon monoxide which can be measured most accurately in engine emission tests and so poor for the other pollutants where different measurement techniques can give very different results.

The measured concentration of carbon monoxide is a factor of 2.8 larger than the analytical value. It is felt that the imprecision with which the surroundings were modeled is the likely cause for this discrepancy (for instance, emissions of automobiles on roadways adjacent to the airport not directly included in the model). Therefore, concentrations due to aircraft emissions alone should be predicted more accurately than concentrations due to all emissions.

EMISSION MODELS CHECKLIST

Input Data Requirements

	Within Program	User Supplies	From AP-42	Proxies/Comments
Vehicle Emission Factors				
-By model year		NP		
-By size class	x	x		
-By power plant	x	x		
-Deterioration factor		NP		
Vehicle Operating Modes				
-Hot/cold start		NP		
-Route average		NP		
-Link average		NP		
-Mode-by-mode	x	x	NP	
Traffic Features				
-Vehicle mix		x		
-Engine operating time	x	x	NP	
-Vehicle miles traveled		x	NP	
-Fuel consumed		NP	NP	
Spatial Distribution				
-Links		x	NP	
-Grinds		x	NP	
-Area		x	NP	

NP = No provision

Output Available

Pollutants	
-CO	Yes
-HC	Yes
-NO_x	Yes
-Particulates	Yes

Availability of Program Documentation

	Yes	No
Included in report		x
Referenced in report	x*	
Language	NP	
Equipment	NP	

Validation/calibration: Los Angeles Airport - 1970 data

Time resolution: 1 hour

Spatial resolution: Airport boundary

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* M. Platt, K. M. Chug, and R. D. Siegel, "Computer Program for the Air Quality Analysis of Airports" (NREC Report No. 1167-2), Northern Research and Engineering Corporation, Cambridge, August 1971.

XV ONTARIO DEPARTMENT OF THE ENVIRONMENT

Information System Descriptive Manual, Air Management Branch, Department of the Environment, Province of Ontario, Canada, January, 1971.

A. Author's Abstract

None given.

B. Summary

The Toronto emissions-inventory methodology considers three source categories: (1) major intense and discontinuous sources (point and line sources); (2) numerous minor sources (area sources); and (3) sources beyond the grid system boundary.

If emissions are greater than 100 lbs per day, the source is considered a point source; otherwise, its emissions are included in area source calculations. The 100 lbs per day criterion may be modified. The Toronto area is divided into 1 kilometer grid squares for area sources, with point sources located on a 5 × 5-kilometer grid to a tenth of a kilometer.

Area sources include emissions from motor vehicles, shipping, railroads, aircraft, and gasoline storage, from space heating and waste disposal of apartments, schools and universities, industrial and commercial sources, and public buildings, and from space heating of residential dwellings. All minor sources within one grid square are summed, and the total is distributed evenly over that square. Line sources are treated as special cases of area sources.

Sources beyond the grid boundary are treated as providing a flux through the border, with assigned source strength and initial vertical

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distribution. These parameters maintain constant values along the length of the border.

The five pollutants considered are sulfur dioxide, nitrogen oxides, particulates, carbon monoxide, and hydrocarbons. Provision is made for sources which, under certain conditions, must switch from their regularly used fuel to another type, thus changing their emission patterns. The information system is designed to accept new data and can modify old data. The capability exists to modify classes of emissions by a fixed percentage.

1. Automotive Emissions

Roadway emissions are divided into five classes: (1) superhighway (line source), (2) other highway, (3) major artery, (4) residential, and (5) business street. Information is collected such as the vehicle count per day for all roads in each grid square (for residential streets a count of 500 is assumed, slightly higher for residential streets with large apartment buildings), and road lengths in each grid square. Yearly emission quantities are found by multiplying the vehicle count per day by road length and by 365, and then applying the emission factor appropriate to the emission class. The hourly or daily emissions are computed using the appropriate diurnal, daily and seasonal factors that have been tabulated.

2. Point and Other Area Source Emissions

Patterns for point source operations, process and nonprocess, were developed based on days of the week in operation and the number of shifts per day. Seasonal and daily space heating variations for both point and area sources were developed using degree day fluctuations, with hourly variations derived from natural gas demand records over 24-hour periods during different seasons. Other area source emission variations were determined in a similar fashion, based upon usage or frequency variation data.

To obtain hourly emissions from the total annual amount of pollutant, the procedure outlined below is applied. The annual total is:

a. Adjusted by a seasonal factor. Depending on the season, one of four seasonal percents (which add to 100) is mulitplied by the annual pollutant total and then divided by 25,

b. Adjusted to a daily rate, by dividing by 365,

c. Adjusted for day of week, using one of the seven percentages associated with a particular day, and

d. Adjusted for weather if a heating emission. For area sources, the factors depend on dwelling type and fuel type. For point sources, fuel combustion emission are adjusted by a space heating percent. This is done by multiplying by the amount of the degree day total and dividing by the degree year total.

e. Only area sources also adjusted by hour of the day. A table of diurnal codes, each containing 24 numbers which add to 100, are applied so that emissions are spread over the hours of the day, based on the components of the code.

C. Model Availability

As stated earlier, the Toronto emissions inventory methodology was developed by the Department of the Environment, Ontario Province, Canada. The emission model is in the form of a computer code, but it is not generally available for public dissemination. Accordingly, the model can only be obtained through a formal request to the Department.

XVI PACIFIC ENVIRONMENTAL SERVICES

Controlled Evaluation of the Reactive Environmental Simulation Model. L. G. Wayne, A. Kokin, and M. I. Weisburd, Final Report, Pacific Environmental Services, Inc., Contract No. 68-02-0345, prepared for Environmental Protection Agency, EPA R4-73-013a, February, 1973.

A. Author's Abstract

The development and validation of an operational version of the Reactive Environmental Simulation Model (REM) were completed. REM was specifically designed to handle large chemical mechanisms to assess the impact on air quality of air pollution control devices, fuels, propulsion systems, stationary sources, and transportation systems where thorough evaluation of emissions, emission constituents and reaction rates are required. The version delivered to the U.S. EPA under this contract contains a mechanism involving 32 reactions, 12 accumulating species, and 12 nonaccumulating species. Larger or smaller mechanisms, also, can be readily inserted into REM for specified purposes.

REM is based on a Lagrangian moving coordinate system which enables the numerical simulation of the chemical reactions that take place in a parcel or column of air moving along a dynamic wind trajectory. The trajectory approach gives REM considerable flexibility and is adaptable for use in a number of practical operational situations. These include short-term air quality forecasting; analysis of the impact of sources of air pollution at various designated locations on the air quality at specified receptor points; interpolation of contaminant concentrations and dosages at locations not covered by air monitoring stations, and control strategy evaluations.

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REM contains such user features as reverse and forward trajectory routines; automatic and objective interpolation from input emission inventory, meteorological and air quality data bases; a chemical dynamics routine capable of accommodating mechanisms based on elementary chemical reactions; and automatic estimation of mixing depth and solar irradiance based on input of local weather and sun angle data.

REM has attained a running time which makes it cost-effective for practical use. On an IBM System 370/155, the real-time-to-simulation ratio for the 31-step mechanism is 150:1; for carbon monoxide alone it is 3000:1; for some of the shorter mechanisms available it should run more than 300:1. The program, also, is user-oriented in that it provides simple input procedures, user documentation, receptor point and time-of-day selectivity, flexibility in treating specific problems, and ability to conveniently select any of an infinite number of trajectories on any number of days of interest. The modular construction of REM, also, makes it easy to add, replace, or delete individual modules. REM can be used as an unlimited receptor point model and to chronicle emission inputs contributing to the air quality at any receptor point.

The validation record of REM over a large number of runs may be summarized as follows:

- CO, less than a factor of 2 in more than 80% of the comparisons; 40% agreement within one part per million.
- O_3, within a factor of 2, 75% of the comparisons.
- NO, within a factor of 2, 75% of the comparisons; 90% agreement within 0.02 ppm.
- NO_2, within a factor of 2, 60% of the comparisons.

The shapes of predicted time profiles of contaminant concentrations are generally similar to those observed at air monitoring stations.

The ease and economy at which REM can be utilized under a variety of data availability situations make potential improvements in accuracy and application possible on a cost-effective basis.

B. Summary

1. Treatment of Source Emissions

A subroutine (module) of the REM program computes emissions of NO, CO, and reactive and less reactive hydrocarbons from freeway and street traffic. Emissions of NO and reactive and less reactive hydrocarbons are calculated for stationary area sources. All urban grid squares are chosen as four square-mile blocks, although the kilometer may also be used as the standatd. Emissions within these squares are viewed as essentially uniform and continuous.

Inputs to the module include time, position of the pollutant column, the distribution of daily traffic on streets and freeways, emission factors, and diurnal usage curves. Traffic and grid system distributions and diurnal curves for the Los Angeles Basin are taken from the emissions treatment developed by Systems Applications, Inc., a review of which appears in this appendix.

Traffic emissions are computed as a function of time by applying the emission factors for the respective pollutants to the traffic levels at the air parcel location, qualified by the daily traffic usage curve. Area source emissions as a function of time are found by applying a constant diurnal usage curve to grid system distributions of average hourly pollutant emissions.

2. Module Method of Operation

Following is the procedure by which pollutants are injected into an air parcel.

1. Initialization (background concentration).

2. Traffic distribution curves are evaluated.

3. The grid in which the trajectory point lies is found.

4. The three closest adjacent grids are found (those with the closest midpoints).

5. The distance from the trajectory point to each grid midpoint is calculated.

6. Is the trajectory point on the midpoint of the grid square in which it lies? If yes, go to step 9; if no continue.

7. The contribution to the parcel from each traffic grid for each pollutant is calculated (the contribution is inversely proportional to the square of the distance from the trajectory point to the grid midpoint).

8. If area sources are to be added, the area source contribution from each grid square for each pollutant is calculated (inversely proportional to the distance squared). Skip to step 11.

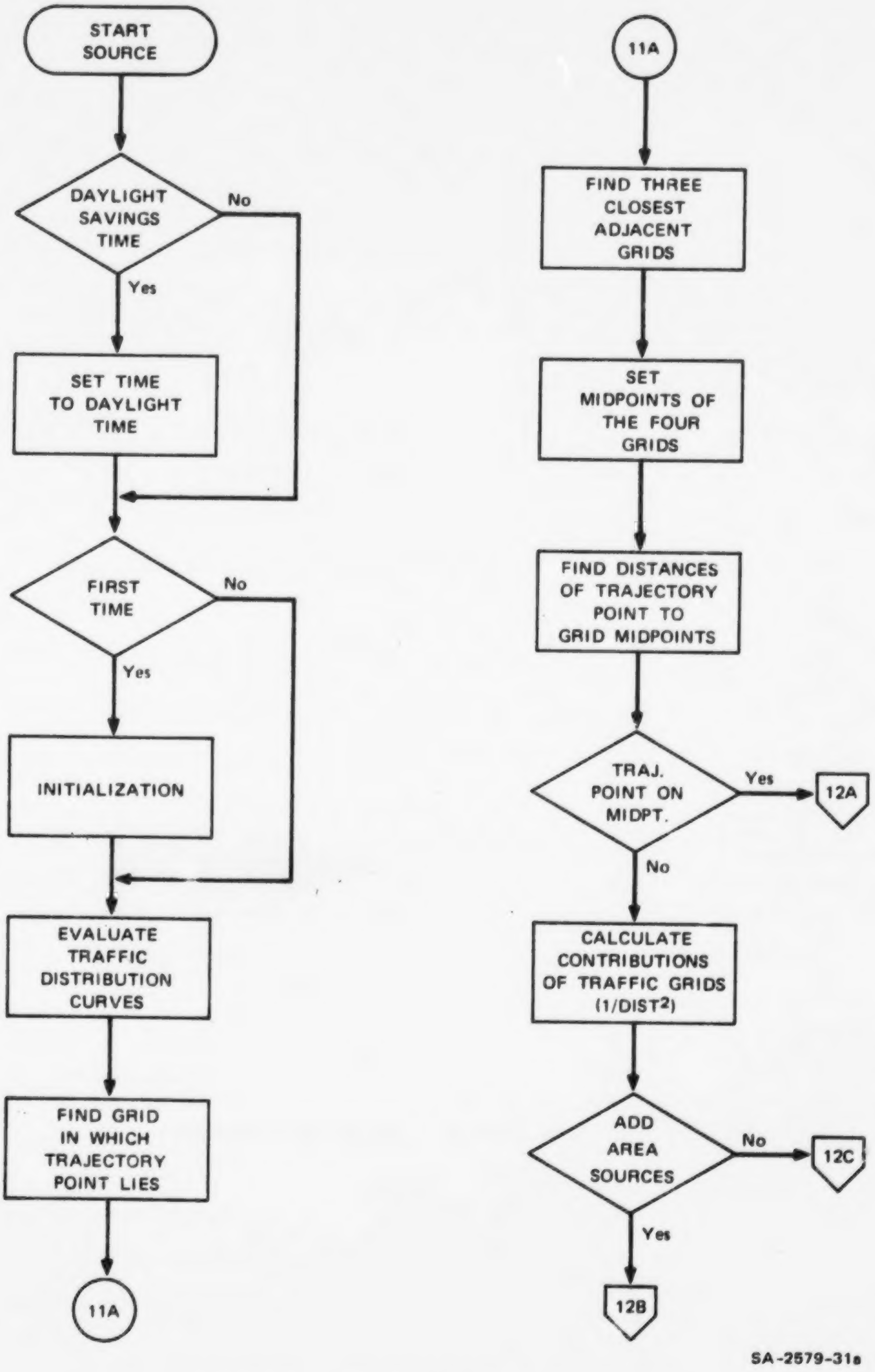
9. The traffic contributions of the trajectory grid only are calculated.

10. If area sources are to be added, the area source contributions of the trajectory grid only are calculated.

11. The traffic and area contributions are then modified by the appropriate diurnal usage curves and added.

C. Model Availability

A computer listing of the emission inventory is included in the supplemental User's Guide of the report.


START SOURCE
DAYLIGHT SAVINGS TIME
No
Yes
SET TIME TO DAYLIGHT TIME
FIRST TIME
No
Yes
INITIALIZATION
EVALUATE TRAFFIC DISTRIBUTION CURVES
FIND GRID IN WHICH TRAJECTORY POINT LIES
11A
11A
FIND THREE CLOSEST ADJACENT GRIDS
SET MIDPOINTS OF THE FOUR GRIDS
FIND DISTANCES OF TRAJECTORY POINT TO GRID MIDPOINTS
TRAJ. POINT ON MIDPT.
Yes
12A
No
CALCULATE CONTRIBUTIONS OF TRAFFIC GRIDS (1/DIST2)
ADD AREA SOURCES
No
12C
Yes
12B

SA-2579-31a

FIGURE B-7 FLOW OF SOURCE SUBROUTINE

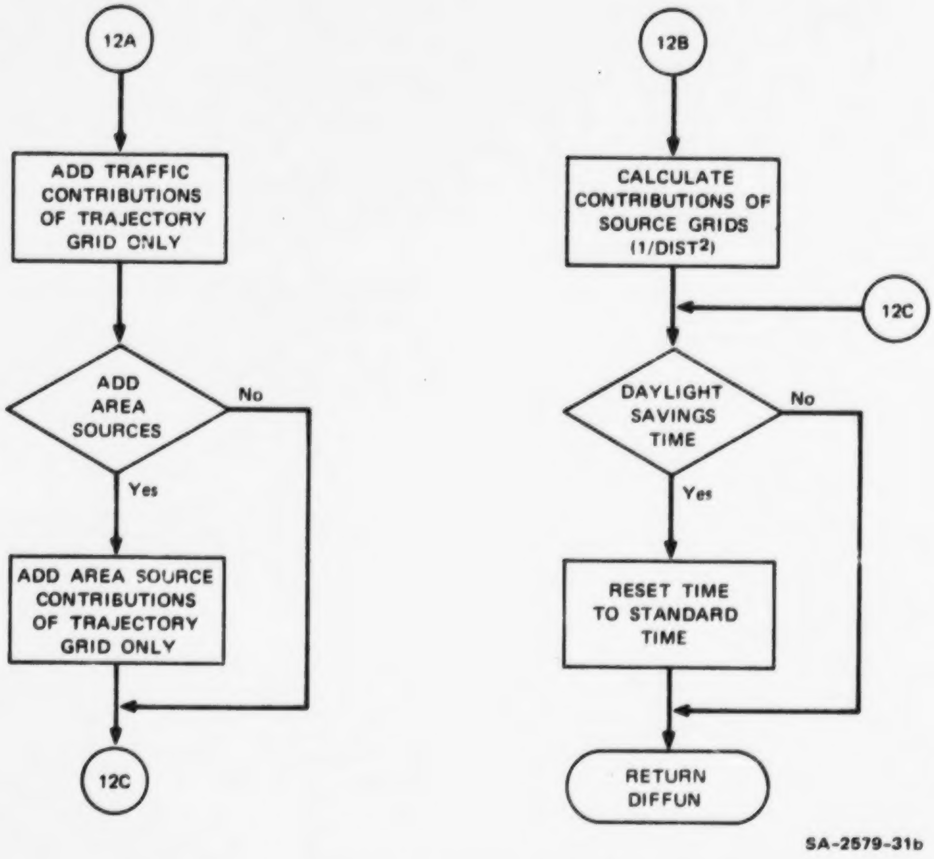

12A
ADD TRAFFIC CONTRIBUTIONS OF TRAJECTORY GRID ONLY
ADD AREA SOURCES
No
Yes
ADD AREA SOURCE CONTRIBUTIONS OF TRAJECTORY GRID ONLY
12C
12B
CALCULATE CONTRIBUTIONS OF SOURCE GRIDS (1/DIST2)
12C
DAYLIGHT SAVINGS TIME
No
Yes
RESET TIME TO STANDARD TIME
RETURN DIFFUN
SA-2579-31b

FIGURE B-7 FLOW OF SOURCE SUBROUTINE (concluded)

XVII RUTGERS UNIVERSITY

Comparison of Air Pollution from Aircraft and Automobiles (Project Eagle). C. Bright et al., Rutgers University, New Brunswick, New Jersey, AD713913, September, 1970.

A. Author's Abstract

None given.

B. Summary

Emissions from either aquadrome or roadway areas are considered to constitute a surface of randomly distributed multiple sources. This surface is assumed to be a uniform area source with respect to a receptor located a variable distance downwind from the edge of the aquadrome or roadway segment.

Emissions are calculated by assuming aircraft passenger load factors and the number of passengers per commuting automobile. The number of passengers and vehicle road or air miles from each source to central locations are used to determine the total number of auto and aircraft miles. This mileage is used to calculate emissions using the following emission factors:

MOTOR VEHICLE EMISSIONS
(gm/passenger mi)

	1970* Emissions	1970† Actual	1975* Goals	1975† Actual	1980* Goals	1980† Actual
Hydrocarbons	8.81	12.10	0.40	8.51	0.20	3.11
Carbon monoxide	38.95	72.35	8.87	45.24	3.79	18.87
Nitrogen oxides	10.35	6.84	0.73	7.84	0.32	3.52
Particulates	0.40	0.47	0.08	0.38	0.02	0.17

TOTAL AIRCRAFT VEHICLE EMISSIONS: APPROACH, CRUISE, TAKE-OFF AT 100% LOAD FACTOR
(gm/passenger mi)

	1970	1975	1980
Hydrocarbons	0.3696	0.3696	0.3696
Particulates	1.0107	1.0107	1.0107
Carbon monoxide	1.4717	1.4717	1.4717
Nitrogen oxides	0.8151	0.8151	0.8151

---

*Based on HEW estimates of emission-controlled vehicles that will be in production at that date.

In converting the grams per vehicle mile to grams per passenger mile, an average automobile passenger occupancy of 1.24 persons is used. For aircraft, occupancy load factors of both 100% and 50% were considered. The 100% load factor was demonstrated to be feasible in the Project Eagle Study. As shown in the tabulation above, the values for aircraft in grams per passenger mile is computed allowing separate emission rates for approach, cruise, and take-off. In converting the grams per vehicle mile to grams per passenger mile, a trip length of 20.8 miles is used for the 53-passenger aircraft. This 20.8-mile trip length represents the average air passenger distance traveled in an urban air transportation system during 7 a.m. to 9 a.m. and 4:30 p.m. to 6:30 p.m. between Manhattan and the 11 transportation centers in Connecticut (Bridgeport, New Haven, and Stamford), New Jersey (Linden/Rahway, New Brunswick, Paterson and Newark), and New York (Farmingdale, Hempstead, Mt. Vernon, and White Plains).

†Based on a methodology considering automobile age and vehicle usage corresponding to automobile age. This procedure is currently being used by the National Air Pollution Control Administration, Durham, North Carolina.

EMISSION MODELS CHECKLIST

Input Data Requirements

	Within Program	User Supplies	From AP-42	Proxies/Comments
Vehicle Emission Factors				
-By model year	x	x		By mix on road for year of study interest
-By size class	x	x		
-By power plant	x	x		
-Deterioration factor	x	x		
Vehicle Operating Modes				
-Hot/cold start		NP		
-Route average	x	x		
-Link average		NP		
-Mode-by-mode		NP	NP	
Traffic Features				
-Vehicle mix		NP		
-Engine operating time		NP	NP	
-Vehicle miles traveled	x	x	NP	
-Fuel consumed		NP	NP	
Spatial Distribution				
-Links		NP	NP	
-Grinds		NP	NP	
-Area	x	x	NP	

NP = No provision

Output Available

Pollutants	
-CO	Yes
-HC	Yes
-NO_x	Yes
-Particulates	Yes

Availability of Program Documentation

	Yes	No	
Included in report		x	Aircraft emission factors based on 1968 NRC work - no program given. Auto emission factors based on NAPCA data.
Referenced in report		x	
Language	NP		
Equipment	NP		

Validation/calibration: None

Time resolution: 4 hours

Area: Tri-State (Connecticut, New Jersey, and New York)

XVIII SACRAMENTO REGIONAL AREA PLANNING COMMISSION

General Inventory of Air Pollution Sources and Emissions. The Air Pollution Threat, Sacramento Regional Area Planning Commission, NTIS No. PB191382, October, 1969.

A. Author's Abstract

The Sacramento Region has three major sources of pollution: transportation, agriculture waste burning, and other stationary sources. The report was directed at estimating the amounts of organic gases, carbon monoxide, nitrogen oxide, sulfur dioxide and aerosols that are emitted from their sources. The predominant emission is carbon monoxide with an estimated 1,215 tons being produced daily. Carbon monoxide is produced mainly from gasoline powered motor vehicles. The other emissions that are produced in the region are organic gases (267 tons/day), nitrogen oxide (87 tons/day), aerosols (46 tons/day), and sulfur dioxide (9 tons/day).

B. Summary

An emission inventory of the Sacramento, California region was compiled for organic gases, carbon monoxide, nitrogen oxides, sulfur dioxide, and aerosol emissions. Sources were classified as transportation, agricultural waste burning, and stationary sources.

The transportation category is divided into gasoline and diesel powered motor vehicles, railroads, and aircraft. Pollutant emission is based on estimates of the different fuels used. Gasoline usage is based on an estimate of 1.1 gallons per day per person. Emission factors for gasoline and diesel powered vehicles take into account existing smog control devices.

Agricultural emissions arise from agricultural waste burning and crop processing, the latter being included with stationary sources. In the Sacramento region 15% of total agricultural waste is burned. Emission figures represent tons of emissions produced on a straight daily average. Seventy-five percent of the burning is done from October to February, with emission figures higher during this season.

Stationary sources include agricultural product processing, where 1% of the total amount of crops processed is estimated as the amount of particulate lost due to processing. Annual figures are divided by the number of days per year to obtain daily values. Emissions from petroleum handling result when tank trucks, service station tanks, and automobile tanks are filled. A daily figure for gallons handled is found by multiplying the population of a region by the estimate of gallons per day per person used. Emissions estimates for solvent use, metal, and mineral processing, and chemical manufacturing are obtained from regional agencies. To estimate emissions from the incineration of solid waste, the total amount of refuse burned daily is found by assuming an average figure of 2 lbs per person per day and multiplying by the population. This amount is divided between municipal dump burning (75%) and backyard burning (25%). Backyard burning is further divided into incinerator, open, and landscape burning. Heating of homes and industrial fuel use are the main sources of emissions from fuel combustion. Natural gas figures are obtained from the utility company, and bottled gas is accounted for either directly or by increasing the yearly utility company figure by 10%. Total daily gas is divided between domestic (75%) and industrial (25%) sources.

C. Model Availability

A computer program for the emissions model is not included.

XIX STANFORD RESEARCH INSTITUTE

A Practical, Multipurpose Urban Diffusion Model for Carbon Monoxide. F. L. Ludwig, W. B. Johnson, A. E. Moon, and R. L. Mancuso, Stanford Research Institute, Menlo Park, California, September, 1970.

A. Author's Abstract

This report describes the development and current status of a receptor-oriented diffusion model that can be applied to urban areas to give the following outputs: (1) carbon monoxide (CO) concentration isopleths for a given set of meteorological conditions and times of day, (2) sequences of hourly CO concentrations at specific locations for given sequences of meteorological conditions, and (3) climatological summaries of CO concentration for specific locations if a historical record of meteorological data is available. The model can be used to obtain the frequency distributions of concentrations averaged over various time intervals for specific hours of the day or days of the week.

B. Summary

Because nearly all urban carbon monoxide emissions are from internal combustion vehicles, the model assumes emissions to be at ground level. Furthermore, the emissions within each segment are assumed to be uniformly distributed. The inventory of vehicular emissions has two components: (1) primary network link emissions from vehicles traveling on the network of major arterial streets and freeways, and (2) secondary background emissions from vehicles traveling over the less densely traveled local and feeder streets.

The primary network links for which the emissions are computed are the sections of major arterial streets and freeways between intersections with other major arterials and freeways. The average length of the links on the primary network is approximately one mile, although the links may be much shorter in densely traveled downtown areas, and more widely spaced in outlying areas. Traffic volumes on links vary hour-by-hour over a day and are different for weekend days than for weekdays. Further, there are smaller seasonal variations. Highway engineers and planners average these variations into a quantity that they call average daily traffic (ADT). For use in the synoptic model, the emissions must be expressed as hourly averages, so the average daily traffic is expressed as a function of time. The amount taken to occur within any given hour is based on the hourly distribution of trips compiled by the traffic study agencies of many areas.

To calculate the contribution of the emissions from traffic links within the five closest segments, the links are first identified with the segments through which they pass. Then the length of the link that lies within a given segment is determined. The emissions within the four segments farthest from the receptor are calculated by a different technique than that used for the closer segments.

Before other computations begin, the city is divided into a grid of one-mile (1.6 km) squares. The traffic link data are used to determine the average daily CO emission in each of these squares. This is accomplished by dividing each link into small increments, less than 0.08-km long. The average daily emission from each of these small pieces is determined by assuming emissions are spread uniformly along the link. Then, the emissions from all the small pieces of link within a square are added together to give total daily emissions for that square. This total is paired in the computer memory with the coordinates of the point at the center of the square. These calculations are done only once for the city.

A trapezoidal grid system is used in the four outer emission segments. As the location of the receptor changes or the wind direction changes, these trapezoidal grids are superimposed on different parts of the fixed city emission grid described in the preceding paragraph. The average emissions at each point on the trapezoidal grid are determined by interpolation between the values at the points on the fixed grid. The average of the emission values determined for the points on the trapezoidal grid defines the emission rate for the segment.

Historical link-volume data are obtained from traffic departments in the cities, towns, and counties in the region being studied. Because traffic varies according to seasonal, weekly, and daily cycles, an observation of volume for one day must be adjusted for the weekly and seasonal fluctuations. The resultant corrected value is recorded as the average daily traffic (ADT) for that location.

The number of vehicle-miles traveled on streets not represented by the primary network is computed from an estimate of the total vehicle-miles traveled in the area and the total vehicle-miles on the links of the primary network. The local street mileage is taken to be the difference between the two.

Link speeds for use in the emission rate calculation are determined from averages of peak and off-peak travel hours on various kinds of route facilities. Speed data were obtained from the traffic survey.

For most locations, the peak traffic hour speeds were taken as equal to 80% of the off-peak speeds. Peak-hour speeds were generally assigned to the four heaviest traffic hours of the day.

The emission rate, e (g/vehicle-mile), is determined from the equation

$$e = c\ S^{\beta}$$

where S is the average speed over the link, in mi/hr, and c and β are constants. For vehicles in use before exhaust control systems, c = 1121 and $\beta = -0.849$, as determined by Rose et al. (1969)[1] from observations on a number of vehicles in several locations. For autos reflecting the level of emission controls mandated for 1968-70, one hundred thirty-nine emission values were calculated from emission data presented by Beckman et al. (1967)[2] and from actual observations of speeds, speed changes, and stops for a variety of road types and traffic congestion conditions. Regression analysis was used to examine the relation between emissions and average speed, both with and without controls. The following power function proved to be the best fit for 1969 model year automobiles:

$$e = 245\ S^{-0.48}$$

---

[1] A. H. Rose and W. D. Krostek, "Emission Factors," U.S. Dept. of Health, Education and Welfare, National Air Pollution Control Administration, p. 5, 1969.

[2] E. W. Beckman, W. S. Fagley, and O. Sarto, "Exhaust Emission Control by Chrysler--The Cleaner Air Package," Air Pollution--1967 (Automotive Air Pollution), Hearings before the Subcommittee on Air and Water Pollution of the Committee on Public Works, United States Senate, Ninetieth Congress, First Session, Part 1, pp. 411-424, 1967.

Consideration of emission control progress yielded the emission model for 1980 and later model year automobiles:

$$e = 34\,S^{-0.48} .$$

C. Model Availability

The APRAC model is fully documented in a recent report by Mancuso and Ludwig[3]. The program is available in two versions: one for the SRI CDC 6400 computer and another for the EPA IBM 360/50.

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[3] R. L. Mancuso and F. L. Ludwig, "User's Manual for the APRAC-1A Urban Diffusion Model Computer Program," CRC/EPA Contract No. CAPA-3-68(1-69), SRI Project 8563, Stanford Research Institute, Menlo Park, California, 1972.

EMISSION MODELS CHECKLIST

Input Data Requirements

	Within Program	User Supplies	From AP-42	Proxies/Comments
Vehicle Emission Factors				
-By model year	x	x		Average CO of vehicle mix for year of study interest
-By size class	x	x		
-By power plant	x	x		
-Deterioration factor	x	x		
Vehicle Operating Modes				
-Hot/cold start		NP		
-Route average		NP		
-Link average		x		Speed and distance
-Mode-by-mode		NP	NP	
Traffic Features				
-Vehicle mix		NP		
-Engine operating time		NP	NP	
-Vehicle miles traveled		x	NP	
-Fuel consumed		NP	NP	
Spatial Distribution				
-Links		NP	NP	
-Grinds		x	NP	
-Area		x	NP	

NP = No provision

Output Available

Pollutants	
-CO	Yes
-HC	No
$-NO_x$	No
-Particulates	No

Availability of Program Documentation[*]

	Yes	No
Included in report		
Referenced in report		
Language		
Equipment		

Validation/calibration: Calculated data were low compared with CAMP-observed data in St. Louis

Time resolution: 1 hour

Spatial resolution: Radial segments-22.5° out to 16 km from receptor point

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[*] See Section C, Model Availability

XX STANFORD RESEARCH INSTITUTE

Procedures for Estimating Highway User Costs, Air Pollution, and Noise Effects. D. A. Curry and D. G. Andersen, NCHRP Report 133, prepared by Stanford Research Institute, 1972.

A. Author's Abstract: None given

B. Summary

Because the researchers were unable to locate data in the proper form, the approach to the estimation of emissions is to compute emissions for a vehicle of a particular type and characterize the emissions from that vehicle as "typical" of the vehicles that will be built during the next few years. The assumption is that the control technology will not change the patterns.

The emission estimating procedure assumes that during the next few years vehicles will achieve carbon monoxide and hydrocarbon control through use of the engine mondification package and a catalytic afterburner, and will achieve nitrogen oxides control through exhaust gas recirculation.

Emission characteristics of a vehicle using the assumed type of engine modification package were obtained for a vehicle manufactured by the Chrysler Corporation. Because most manufacturers are using this type of control, it is assumed that the vehicle is typical in that regard.

The emissions for stopping and changing speeds were computed under the assumption that slowing down and speeding up would occur under constant acceleration conditions. The emissions added due to speed changes were computed by applying the emission characteristics of the test vehicle to the pattern of speed changes analyzed elsewhere in the report and by characterizing the results by the best straight line that could be drawn

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through the emission values plotted against volume to capacity (v/c) ratio for each type of facility.

The reference emissions provide an estimate of the pounds of each pollutant generated by travel over the analysis segments if all of the traffic consisted of automobiles meeting the exhaust emission control requirements for the 1969 model year. The table below gives the emission limits in grams per mile and their relative ratios for various model years as used in the conversion procedure (the ratios do not always track the emission limits exactly, owing to changes in test procedures). These relative values were combined with the fraction of the vehicle population represented by each model year as predicted by averaging the fractions for the years 1966-1970.

AUTOMOBILE EMISSION LIMITS FOR VARIOUS MODEL YEARS

	Actual or Permissible Emission (gm/mi)			Emission Factor Used (1970=1.0)	
Model Year	HC	CO	NO_x	HC and CO	NO_x
1967 and earlier	13.6	117	4.0	3.5	1.0
1968 and 1969	5.1	59	4.0	1.5	1.0
1970	3.4	39	4.0	1.0	1.0
1971-72	3.4	39	4.0	1.0	1.0
1973-74	3.4	39	3.0	1.0	0.75
1975	0.41	3.9	3.0	0.1	0.75
1976-79	0.41	3.9	0.4	0.1	0.1
1980 and later	0.20	2.0	0.2	0.05	0.05

Use of the conversion factor assumes that the future controls will reduce emissions proportionally for all operating conditions. Use of a catalytic afterburner for control of carbon monoxide and hydrocarbons will result in emissions that approximate this assumption.

The emissions for single-unit gasoline trucks were estimated to be 2.5 times those of the reference automobile under all conditions.

The last step was to incorporate a degradation factor for the predicted increase in vehicle emissions due to wear, derived from data of Rose and Krostek.[1] The degradation factor increases at a decreasing rate with average mileage drive, and hence with age:

Vehicle Age (yr)	Degradation Factor
0	1.00
1	1.05
2	1.12
3	1.18
4	1.20
5	1.22
6	1.23
7	1.24
≥ 8	1.25

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[1] A. H. Rose, Jr. and W. D. Krostek, "Emission Factors," Department of Health, Education, and Welfare, June, 1969.

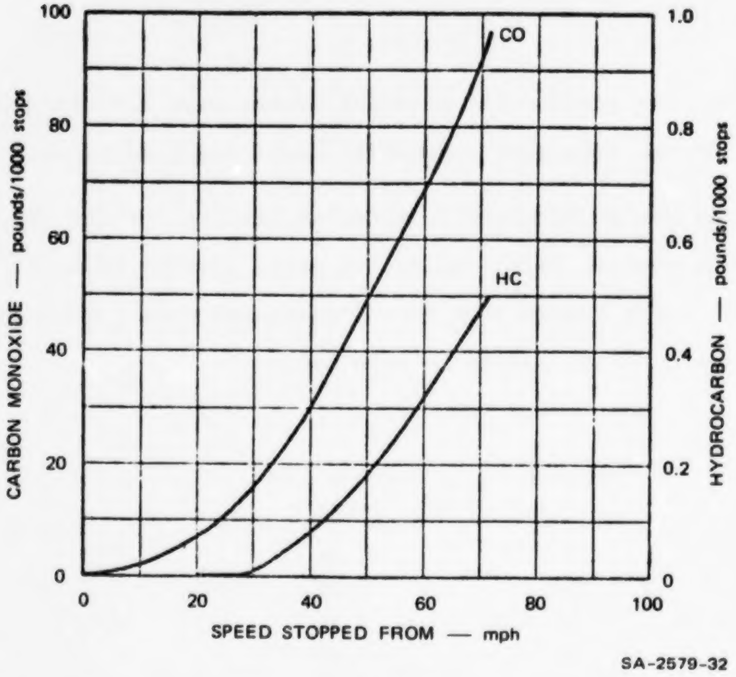


FIGURE B-8 AUTOMOBILE HYDROCARBON AND CARBON MONOXIDE EMISSIONS ADDED PER 1,000 STOPS

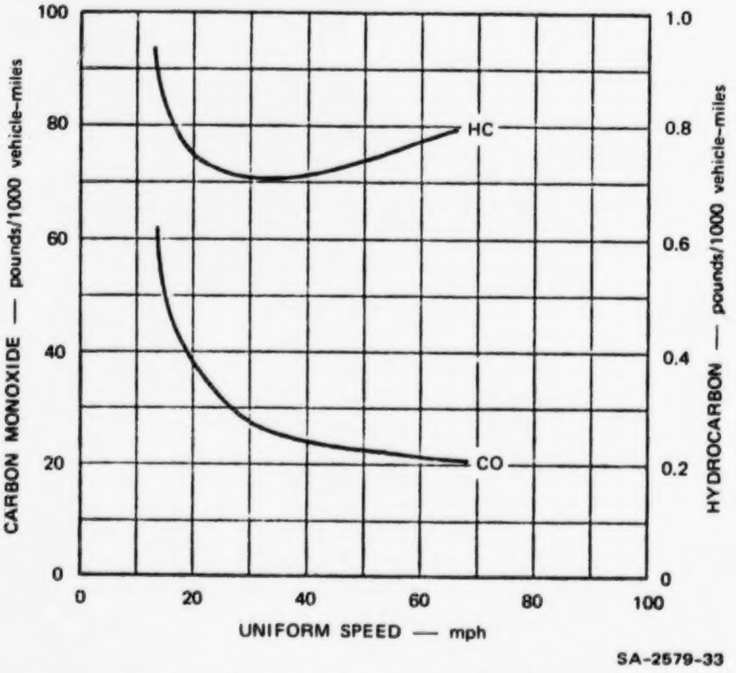
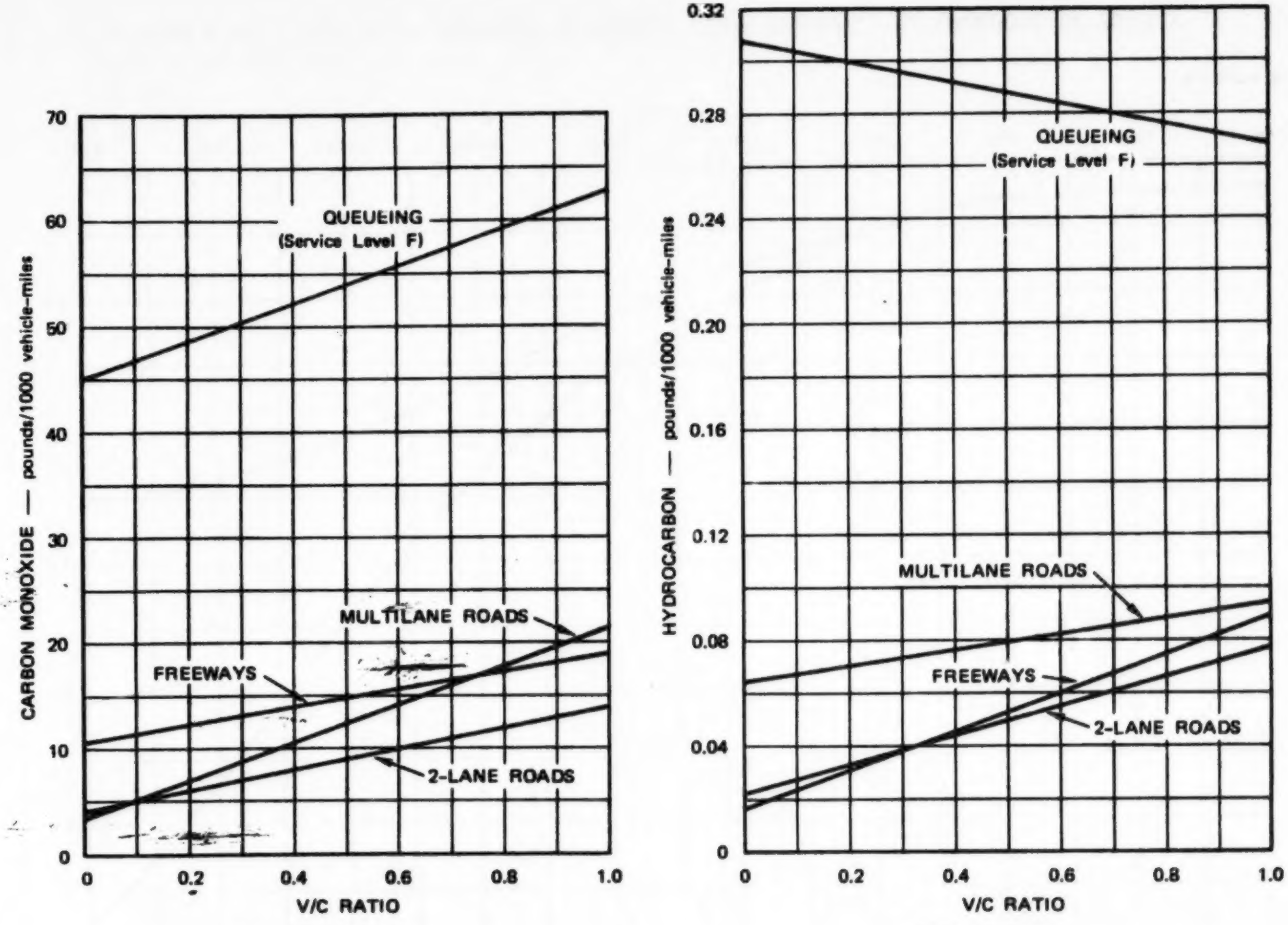


FIGURE B-9 AUTOMOBILE HYDROCARBON AND CARBON MONOXIDE EMISSIONS PER 1,000 MILES OF DRIVING AT UNIFORM SPEED

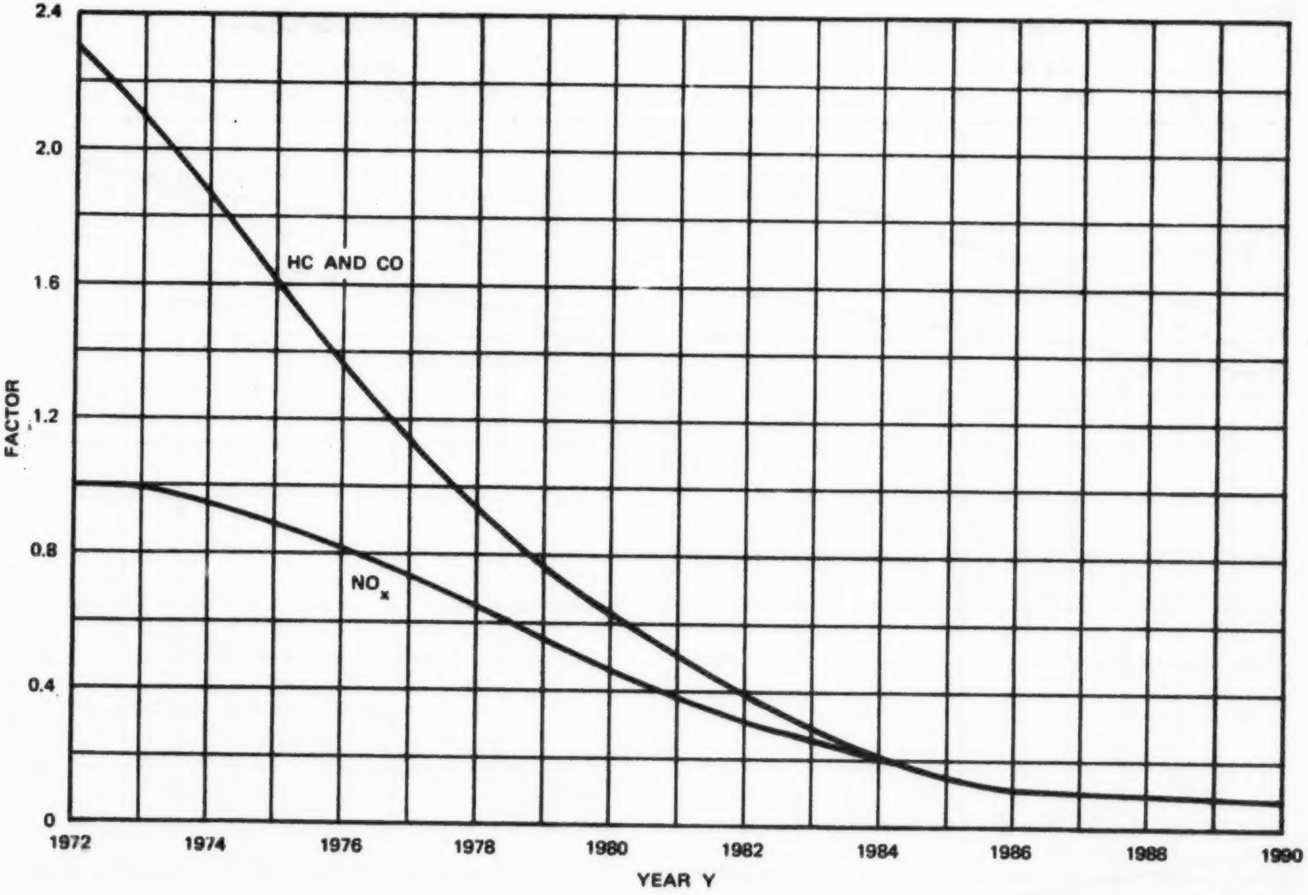


CARBON MONOXIDE

HYDROCARBON

SA-2579-39

FIGURE B-10 AUTOMOBILE EMISSIONS ADDED FROM SPEED CHANGES PER 1,000 VEHICLE-MILES



SA-2579-36

FIGURE B-11 FACTOR TO CONVERT REFERENCE YEAR EMISSIONS TO EMISSIONS IN YEAR Y

EMISSION MODELS CHECKLIST

Input Data Requirements

	Within Program	User Supplies	From AP-42	Proxies/Comments
Vehicle Emission Factors				
-By model year	x			Based on 1969 reference auto, conversions supplied for other years
-By size class	x			
-By power plant		NP		
-Deterioration factor	x			
Vehicle Operating Modes				
-Hot/cold start		NP		
-Route average		NP		
-Link average		NP		
-Mode-by-mode		x	NP	
Traffic Features				
-Vehicle mix		x		
-Engine operating time		NP	NP	
-Vehicle miles traveled		x	NP	
-Fuel consumed		NP	NP	
Spatial Distribution				
-Links		x	NP	
-Grinds		NP	NP	
-Area		NP	NP	

NP = No provision

Output Available

Pollutants	
-CO	Yes
-HC	Yes
-NO_x	No
-Particulates	No

Availability of Program Documentation

	Yes	No
Included in report		x
Referenced in report		x
Language	NP	
Equipment	NP	

Validation/calibration: None

Time resolution: 1 hour

Spatial resolution: Link

XXI STANFORD RESEARCH INSTITUTE

A Preliminary Study of Modeling The Air Pollution Effects From Traffic Engineering Alternatives. F. L. Ludwig, R. C. Sandys, and A. E. Moon, Stanford Research Institute, Menlo Park, California, Air Pollution Control Association Journal, Vol. 23, No. 6, pp. 499-504, June, 1973.

A. Author's Abstract

Three separate mathematical models were combined to calculate the changes in carbon monoxide (CO) concentrations that might result from traffic engineering changes. The three models used were: (1) The Dynamic Highway Transportation Model (DHTM) which relates traffic flow patterns to physical parameters and traffic signal characteristics of a network; (2) an emission model that predicts CO emissions from traffic flow parameters such as number of stops, idling time, etc.; and (3) the APRAC-1A urban diffusion model which calculates CO concentrations from source distributions and meteorological factors. The composite model was applied to traffic in downtown Chicago for a specific set of meteorological conditions. Results are compared for two traffic signal control schemes. In those blocks where concentrations were highest, the model indicates a 20% reduction is possible through improved traffic signal controls. The model should be useful for testing other traffic control measures.

B. Summary

Moon[1] has presented a methodology for calculating the amount of CO generated by a "reference" automobile under four conditions: idling, steady cruising, stopping, and starting. The third and fourth conditions can be combined, with the results expressed as the amount of CO emitted per vehicle stop. Because of continual changes in the pollution control devices required for cars, and the changing mix of vehicle-model years, it is necessary to convert emissions for "reference" cars to averages for a particular year. The appropriate conversion factors have been provided in Reference 1.

---

[1] D. A. Curry and D. G. Andersen, "Procedures for Estimating Highway User Costs and Air and Noise Pollution Effects," Final Report, Highway Research Board Project 708, Stanford Research Institute, Menlo Park, California, 1971.

According to Moon, 0.15 gram per second (gm/s) of CO are released by an idling vehicle. The amount of CO released by a vehicle traveling at a steady speed is a function of that speed. Figure 1 shows an approximation of the function; the curve has been fitted with exponential functions to simplify the calculations. At the low speeds, below about 7 or 8 mph, the curve shown is based on the assumption that a slowly moving vehicle emits CO at the same rate as an idling vehicle; thus, the emissions per vehicle-mile will be inversely proportional to the speed. The emissions for each vehicular stop (and subsequent start) are an exponential function of the steady driving speed from which the stop was made.

A factor is used to convert emissions of CO from a vehicle made in the reference year (1968) to emissions for years after 1971. The factor accounts for the mixture of vehicles manufactured in different years, based on national averages of vehicle life expectancy. It is based on existing legislation for the 1970 to 1975 era and on expected further limitation on emissions through 1980, and assumes no retrofit requirements.

Moon's emissions model can calculate the emissions of CO on a given street segment, given:

1. Number of vehicle-miles of steady-speed driving on the link
2. The speed achieved during steady-speed operation
3. The number of stops and starts during the hour
4. The number of vehicle-seconds spent stopped and idling.

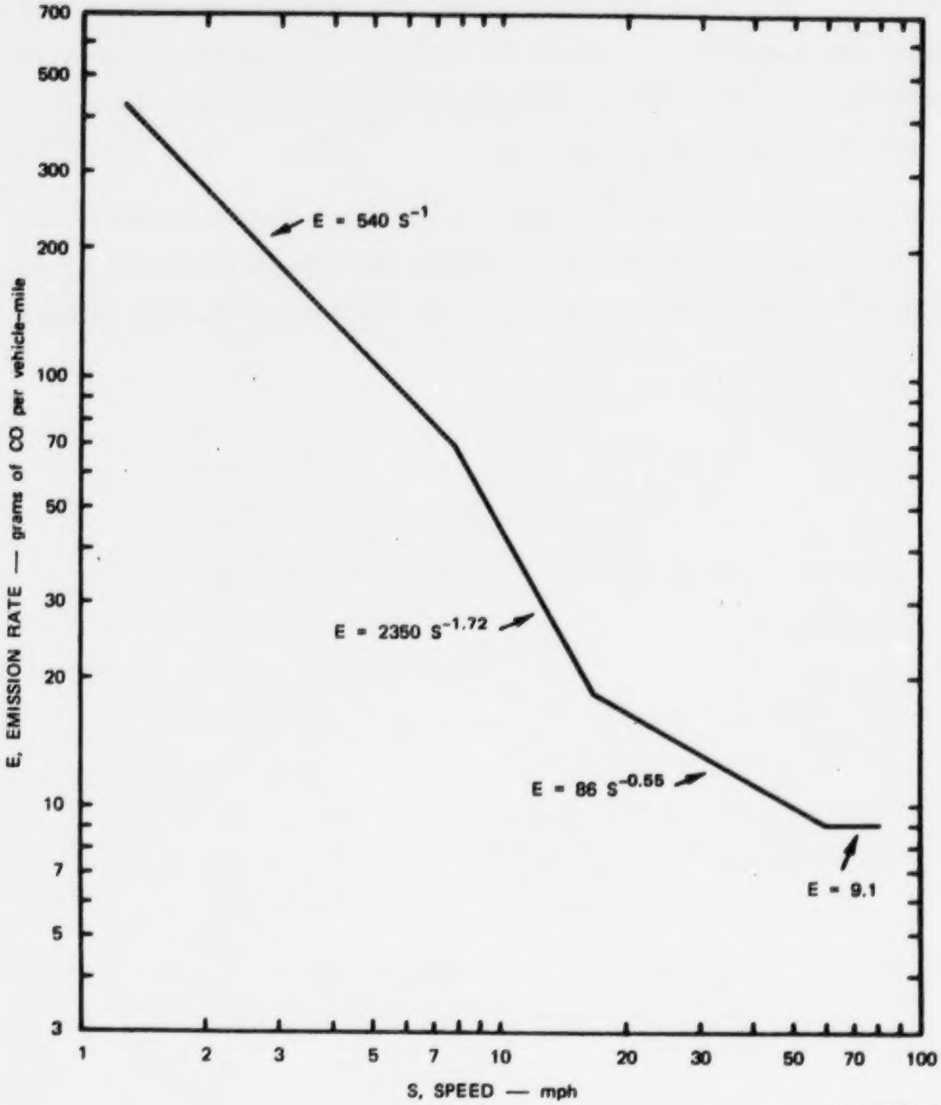


FIGURE B-12 RELATIONSHIP BETWEEN CARBON MONOXIDE EMISSIONS AND STEADY-SPEED DRIVING

The Dynamic Highway Transportation Model can provide the above items of information. For this study, an intermediate computer program was written to accept the magnetic tape output of the DHTM and create a punch card deck for input to the APRAC-1A Diffusion Model; this is not the most efficient method of treating the problem.

This model is offered for central business district applications. For the outlying streets, the method using the formula developed by Rose and Krostek[2] to relate emissions to average speeds and traffic volumes is considered adequate.

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[2] A. H. Rose, Jr. and W. D. Krostek, "Emission Factors," Department of Health, Education, and Welfare, June 1969.

EMISSION MODELS CHECKLIST

Input Data Requirements

	Within Program	User Supplies	From AP-42	Proxies/Comments
Vehicle Emission Factors				
-By model year	x	x		1968 Reference; factored to later years
-By size class		NP		
-By power plant		NP		
-Deterioration factor		NP		
Vehicle Operating Modes				
-Hot/cold start		NP		
-Route average		NP		
-Link average		NP		
-Mode-by-mode		x >	NP	Starts; stops; idling; steady-state speed; vehicle miles/ link
Traffic Features				
-Vehicle mix		NP		
-Engine operating time		x	NP	
-Vehicle miles traveled		x	NP	
-Fuel consumed		NP	NP	
Spatial Distribution				
-Links		x	NP	
-Grinds		NP	NP	
-Area		NP	NP	

NP = No provision

Output Available

Pollutants	
-CO	Yes
-HC	No
-NO_x	No
-Particulates	No

Availability of Program Documentation

	Yes	No
Included in report		x
Referenced in report		x
Language	NP	
Equipment	NP	

Validation/calibration: None

Time resolution: 1 hour

Spatial resolution: Intersection

XXII SYSTEMS APPLICATIONS, INC.

(1) Contaminant Emissions in the Los Angeles Basin--Their Sources, Rates, and Distribution. P. J. Roberts, P. M. Roth, and C. L. Nelson, Appendix A., "Development of a Simulation Model for Estimating Ground Level Concentrations of Photochemical Pollutants," Systems Applications, Inc. Report No. 71 SAI-6, Contract No. CPA 70-148, prepared for the Environmental Protection Agency, March 1971.

(2) Extensions and Modifications of a Contaminant Emissions Model and Inventory for Los Angeles. P. J. Roberts, M. Liu, S. D. Reynolds, and P. M. Roth, Appendix A, "Further Development and Validation of a Simulation Model for Estimating Ground Level Concentrations of Photochemical Pollutants," Systems Applications, Inc., Report No. R73-15, Contract No. 68-02-0339, prepared for the Environmental Protection Agency, January, 1973.

A. Author's Abstract

(1) Perhaps the most tedious and mundane aspect in the development and validation of a simulation model of reaction and dispersion processes in the atmosphere is the compilation of a complete contaminant emissions inventory. Yet, such an inventory is a sine qua non in model validations and, if done properly, the emissions estimates probably constitute the most precise segment of requisite input data. Contrast, for example, the relatively low magnitudes of errors in emissions estimates with the imprecision of wind speed and direction estimates, both at the surface and aloft, as well as with the uncertainties in estimates of the variation in mixing depth with location and time. Furthermore, as emissions inventory need be carried out but once to serve as an adequate representation of a region, whereas meteorological data must be collected for each validation day, and for the purposes of this modeling venture, represented through hourly variation in wind field and mixing depth. It thus seemed wise

to put a considerable effort into the establishment of an accurate emissions inventory for the Los Angeles Basin.

Particular emphasis was placed on developing a detailed representation of the spatial and temporal traffic distribution in the Basin, as vehicular emissions account for approximately 97% of CO; 85% of reactive hydrocarbon, and 62% of NO_x emissions. Attention was also given to those sources which, while responsible for only a small proportion of emissions on an area-wide basis, contribute heavily to pollutant concentration levels in their own locale--airports, power plants, and refineries. In this Appendix, we present in detail the emissions inventories developed for the major moving and fixed sources of pollution in the Los Angeles Basin.

(2) During the last months of 1970, we prepared a pollutant emissions inventory for the Los Angeles Basin for use in the modeling of the transport, diffusion, and reaction of atmospheric contamination. Pollutant sources were grouped into five categories--automobiles (and other motor vehicles), aircraft, power plants, refineries and distributed fixed sources. Emissions rates for a 2x2-mile grid system covering the Basin were compiled for nitrogen oxides, carbon monoxide, and hydrocarbons. Temporal variations in emissions rates were also determined. The complete inventory is reported in "Contaminant Emissions in the Los Angeles Basin--Their Sources, Rates, and Distribution," by P.J.W. Roberts, P. M. Roth, and C. L. Nelson (1971).

Early in 1972, we had the opportunity to make a number of modifications and extensions for the emissions inventory. The changes which affected all segments of the original inventory, were motivated by a variety of factors, but most heavily by a desire to improve the accuracy or the resolution of the inventory, or to correct errors. It is the purpose of this report to document all modifications and extensions that were implemented. In general, this report is segmented similarly to its predecessor, the exceptions being that (1) changes applicable to all portions of the inventory are included in an introductory general section and (2) the one modification to the refinery inventory as a matter of convenience, is included in the section dealing with distributed fixed sources. Finally, we wish to point out that only changes are reported here; we have not attempted to present a final version of the inventory, either in summary or in detail, in this document. One must read both this report and the original to construct the complete inventory.

B. Summary

The emissions model developed by SAI considers both fixed and moving sources of air pollution in the Los Angeles Basin. Fixed sources are characterized as area sources, with the exception of point source power plant emissions, which are treated as volume sources. Both automotive and aircraft emissions are distributed over an array of grid squares. Concentrations of carbon monixide, hydrocarbons and nitrogen oxides are predicted, using hourly emissions estimates.

1. Treatment of Automotive Emissions

Automotive emissions are estimated for 2.0x2.0-mile grid squares and are assumed to be attributable to exhaust, crankcase leakage (blow-by) and evaporation. The Federal Driving Cycle (FDC) is adopted.

a. Exhaust Emissions

Surface Streets. Average emission rates for surface streets are estimated by calculating

$$Q_i^a(t) = y(t)Q_i^c + [1-y(t)]Q_i^h$$

where y(t) equals the fraction of cars started at time t that are "cold-started" (superscript c); the relation between cold-start and hot-start (superscript h) emissions is:

$$Q_i^h = Q_i^c \left[\frac{zP_i^h + (1-z)T_i}{zP_i^c + (1-z)T_i} \right]$$

where z = fraction of vehicle registration that are automobiles

P_i^h, P_i^c = hot-running and cold-start auto emission rates

T_i = emission rates from trucks and buses

Both Q_i^c and Q_i^h are based on the FDC, which is defined to simulate a trip having an average speed of about 19.6 mph.

A variation exists in the emissions rate due to the non-uniform distribution of cold vehicle starts during the day. To account for this, a correction factor, $\beta_i(t)$, is formulated.

An integral representing the average emissions rate for each vehicle is derived, relating the emissions from a vehicle during a time interval after a cold-start, ϵ_i^c, to those after a hot-start, ϵ_i^h. Functional forms for ϵ_i^c and ϵ_i^h are established, giving a linear decrease in ϵ_i^c during the first 7-1/2 minutes of operation and a constant emissions rate thereafter, equal to ϵ_i^h. The integral is approximated by an expression for the average emissions rate at the midpoint of a 15-minute time interval that assumes that the trip start time is uniform during the time interval. The correction factor is defined as this approximation divided by the average emissions rate.

This treatment considers the effect of vehicle start variation only for the period 6 a.m. to 9:23 a.m. The "midday bump" and evening rush hour variations are not considered because the model was not validated for that time period. Also, it should be noted that large quantities of data are needed to properly evaluate $\beta_i(t)$. Pertinent data include driving patterns in an area, trip length, average speed, time between trips, emissions data as functions of time for both hot-

and cold-starts, etc. Since large quantities of this data are not generally available, the authors have made simplifying assumptions.

The correction factor is

$$\beta_i(t) = \frac{E_i^s(t)}{Q_i^s(t)}$$

where $Q_i^s(t)$ is the average emissions rate as defined previously, and

$$E_i^s\left(t_n\right) = \frac{\frac{c_{n-2}}{30}\,\varepsilon_i^h + c_{n-1}\left[\left(1-y_{n-1}\right)\varepsilon_i^h + y_{n-1}\,\bar{\varepsilon}_i\right] + \frac{c_n}{2}\left[\left(1-y_n\right)\varepsilon_i^h + y_n\,\tilde{\varepsilon}_i\right]}{\frac{c_{n-2}}{30} + c_{n-1} + \frac{c_n}{2}}$$

where n = a fifteen-minute time interval

$E_i^s\left(t_n\right)$ = average emissions rate of species i evaluated at the mid-point of time interval n

c_n = total number of trips started in a time interval

y_n = ratio of cold-starts to total starts during a time interval

$\varepsilon_i^h(t)$ = emission from a vehicle during a time interval after a hot-start

$\bar{\varepsilon}_i$ = average emissions rate of species i from an automobile over the time period between 7-1/2 and 22-1/2 minutes after a cold start

$\tilde{\varepsilon}_i$ = average emission rate of species i from an automobile over the time period between zero and 7-1/2 minutes after a cold-start

The ε_i^h and ε_i^c values are derived on the basis of the FDC, and $\bar{\varepsilon}_i$ and $\tilde{\varepsilon}_i$ follow from these. Values of c_n are based on an analysis of data by Kearin et al. (1971)*, where the weekday was segmented into

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* D. H. Kearin, R. L. Lamoureux, B. C. Goodwin, "A Survey of Average Driving Patterns in Six Urban Areas of the United States: Summary Report", Report TM-(L)-4119 Vol. 7, System Development Corp., Santa Monica (January 1971).

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eight time periods, each with an assigned constant value of y.

The total emissions from surface streets for a particular grid square are

$$E_i^s(t) = \frac{1}{60} Q_i^s(t) d_\ell^s(t) M^s \beta_i(t)$$

where $d_\ell^s(t)$ = fraction of daily nonfreeway traffic count assignable to an hourly period

M^s = nonfreeway vehicle mileage per day for the grid square in question

Values of $d_\ell^s(t)$ are based on an average of 52 randomly selected streets (the sample being stratified according to the magnitude of daily traffic flow), the counts on individual streets being weighted in proportion to the magnitude of traffic flow on the street. Traffic counts were taken from state and city data.

Freeways. In calculating freeway emissions, all vehicles are assumed to be hot-running. It has been found that average emissions rates for freeways in Los Angeles correlate well with average route speed alone, although many other factors influence these rates.

Freeway emissions rates for species i for a particular grid square are given by

$$E_i^f(t) = \frac{1}{60}\left\{ n_f(t)\alpha_i[\bar{v}(t)] + n_s(t)\alpha_i[\bar{v}_s(t)]\right\}$$

$$\alpha_i = a_i(\bar{v})^{b_i}$$

where $\bar{v}_f, \bar{v}_s$ = average speed in the fast and slow directions, respectively

n_f, n_s = number of vehicle miles driven per hour in the fast and slow directions, respectively

α_i = hot-running emissions rate of species i

a_i, b_i = empirically determined constants

"Fast" and "slow" refer to an assignment of names to the two opposing directions of flow on a freeway.

$$n_f = \frac{N_\ell^f}{1+x}$$

$$n_s = \frac{\left(N_\ell^f\right)x}{1+x}$$

$$N_\ell^f = d_\ell^f M^f$$

where d_ℓ^f = fraction of daily freeway traffice counts assignable to an hourly period

M^f = freeway vehicle mileage per day for a grid square

$x = n_s/n_f$

The average vehicle flow as a function of time for both directions on all freeways in the Los Angeles Basin is calculated from 15-minute count data for a 24-hour period at 31 locations. Values of x are computed using these data. Average freeway speed as a function of time for both freeway directions was obtained from state division of highways data.

To determine the constants a_i and b_i, average emissions rates for hot-running conditions at a known average speed are necessary. These rates were estimated in the same manner as those for surface streets. Also required are the slopes of emissions rate/average speed curve. Data for these are very scarce, and the best such data available are somewhat out of date (less than 50% of the vehicles on the road in

September, 1969, are represented by the test group). Correlations based on the data give estimates of average emissions rates at high speeds under hot-running conditions that appear to be rather low. The authors decided to modify the values, basing their modifications on the premise that automobile manufacturers design their systems with the expectation that they will be tested at low average speeds. Thus, it may be expected that average emissions rates at low speeds have decreased more rapidly from year to year than rates at high average speeds. Since there is no data on which to base estimates of revised slopes b_i, they are estimated using two points, the hot-running emissions rates at 19.6 mph and the rates at 60 mph, the latter computed from

$$Q_i^h(60) + 1/3 \left[Q_i^h(19.6) - Q_i^h(60) \right]$$

where Q_i^h (19.6) are the FDC values, modified for hot-running conditions, and $Q_i^h(60)$ are computed from the data described above. The factor one-third is purely a guess and could range from 0.1 to 0.5.

Total Exhaust Emissions. Total vehicle emissions for a particular grid square are given by

$$E_i(t) = E_i^f(t) + E_i^s(t)$$

b. Crankcase Emissions

It is estimated that 15% of all automobiles are not equipped with PCV devices. This study uses a figure of 0.7 gm/mile for the average vehicle in the Los Angeles Basin.

c. Evaporative Losses

Evaporative losses are the sum of fuel tank losses and carburetor losses, and involve only hydrocarbons. The authors assume that these losses occur mainly during the hours 7 a.m. to 7 p.m. PDT, and that they are distributed evenly over this period. Evaporative emissions in each square are assumed to be proportional to the number of nonfreeway vehicle miles in that square.

$$\begin{pmatrix}\text{evaporative}\\ \text{emissions for}\\ \text{square i,j}\end{pmatrix} = m_{ij}\,\frac{\begin{pmatrix}\text{number of}\\ \text{automobiles}\\ \text{registered}\end{pmatrix}\begin{pmatrix}\text{evaporative}\\ \text{losses}\end{pmatrix}}{\begin{pmatrix}\text{total nonfreeway}\\ \text{vehicle mileage}\end{pmatrix}}$$

where m_{ij} equals thousands of nonfreeway vehicle miles per day driven in square ij.

2. Treatment of Aircraft Emissions

Hourly emissions from airport operations are classified as arising from ground and airborne operations. For each class of aircraft it is assumed that pollutants are emitted at a uniform rate during each of five operating modes; the amount of contaminants injected into a cell is thus proportional to the length of the flight path in that cell. Aircraft emissions are treated as volume sources, well-mixed in their cells, and are assumed to occur at a uniform rate over each 1-hour time period. Emissions indices measured from one aircraft are assumed representative of all aircraft of that class.

a. Ground Operations Emissions

Ground operations are assigned three modes of operation: taxi, landing, and take-off. The taxi mode includes taxi between runway and satellite upon landing, between satellite and end of runway and awaiting clearance for take-off, and idle at satellite. The landing mode includes emission from touchdown on the runway to turn-off from the runway, with the take-off mode being the reverse.

Ground operation emissions rates into ground cell $ij\ell$ for an hourly period are

$$Q^{k}_{ijm,\ell,m=1} = \frac{10^{-3} d_{\ell} a_{ij}}{K} \sum_{u=1}^{7} n_{u} M_{u} \sum_{g=1}^{3} f^{k}_{gu} C_{gu}$$

where i,j are indices for the x,y coordinates

m is an index for the z coordinates (= 1 for ground cells)

ℓ is an index for the hourly period

k refers to the type of pollutant (CO, HC, NO, and NO_2)

g refers to ground operation mode (taxi, landing, and take-off)

u refers to aircraft class (long-range jet transport, medium-range jet transport, business jet, turboprop transport, piston engine transport, piston engine utility, and turbine engine helicopter

$Q^{k}_{ijm\ell}$ = emissions rate

d_{ℓ} = fraction of total daily flights in an hourly time period

A_{ij} = fraction of airport area belonging to a ground cell

K = 60 (min/hr)

n_{u} = number of flights per day of aircraft class u

M_{u} = average number of engines per aircraft class u

f^{k}_{gu} = pounds of pollutant k emitted per 100 lbs of fuel consumed by aircraft class u operating in mode g

C_{gu} = pounds of fuel consumed per engine of aircraft class u operating in mode g

b. Flight Operations Emissions

The modes of operation for airborne operations are an approach mode and a climb-out mode. It is assumed that arrival and departure rates within each time period are equal; that aircraft follow straight-line flight paths while in approach and climb-out modes; and that ascent and descent angles for all aircraft at a particular airport are equal to those of the aircraft class having the highest fraction of total operations at that facility. Other assumptions are that flight paths originate and terminate at the most frequently used runway at each airport; that a fixed proportion of aircraft of a given class arrive and depart from each airport; and that an unknown temporal distribution of flight operations at an airport may be represented by the temporal distribution from another airport having a similar mix of aircraft by class.

Emissions rates for airborne flight operations are given by

$$Q^k_{ijm\ell} = \frac{10^{-3} d_\ell P_{ijm}}{K} \sum_{u=1}^{7} n_u M_u f^k_u C_u \frac{t_u}{t'_u},$$

where t_u = time spent in descent from inversion height to touch-down by aircraft of class u

t'_u = time spent in descent from 3000 feet above ground elevation to touchdown by aircraft of class u

f^k_u = pounds of pollutant k emitted by aircraft of class u per 1000 lbs fuel consumed during descent

C_u = pounds of fuel consumed per engine of aircraft of class u during descent from 3000 feet

P_{ijm} = fraction of the length of the flight path assignable to cell ijm

The above equation also describes the emissions rate during climb-out, with the appropriate changes in the definitions of t_u, f^k_u, t'_u and C_u.

3. Treatment of Fixed Source Emissions

a. Power Plants

Emissions from point source power plants are distributed evenly as volume sources in the column of cells up to the inversion base, under the assumption that the plume is well mixed in these cells. Since diurnal variations in NO_x emissions were substantial, hourly emissions averages for the two seasons in some plants and for one day in others are used as source strengths and apportioned as described above.

b. Oil Refineries

Refinery emissions are treated as area sources and are assumed to be well mixed in the cell into which they are injected. Total daily emissions for nitrogen oxides and low and high reactivity organic gases and the individual refinery crude capacities were available from the Los Angeles County Pollution Control District. The total emissions are distributed uniformly over 24 hours and in proportion to the crude capacity of each refinery.

c. Distributed Sources

Additional sources are treated uniformly as area sources. Since some of the emissions from these sources are spread over highly populated areas, the modeling area was divided into regions of high and low population density.

Petroleum Marketing, Domestic, Ship and Railroad Emissions--Nitrogen Oxides. It is assumed that half of the total daily domestic emissions and the total daily emissions attributable to petroleum marketing operations occur between 6 a.m. and 6 p.m. PST. Half of the daily ship and railroad emissions are assumed to occur at the Port of Los Angeles. The emissions cited above are distributed uniformly over the high-population grid square. All emission rates are assumed to be uniform between 6 a.m. and 6 p.m. PST.

Incineration--Nitrogen Oxides. The authors assume that the total daily emissions occur between 6 a.m. and 6 p.m. PST, and that emission rates are constant. In Los Angeles County, emissions assignable to a grid square are proportioned to the number of permit units issued for the 5-mile square area containing that grid square. Due to lack of information on the spatial distribution of industrial plants in Orange County, emissions are assumed to be released in the highly populated squares.

Mineral Processing Plants and Metallurgical Plants--Nitrogen Oxides. These emissions are apportioned for each county in the same manner as incineration emissions.

Petroleum Production and Other Industries--Nitrogen Oxides. Petroleum production emissions are also apportioned in the same manner as incineration emissions, but are distributed uniformly over 24 hours. Other industries contribute emissions which are distributed uniformly between 6 a.m. and 6 p.m. PST, mainly over the south central portion of Los Angeles County, with smaller amounts in other areas.

All Fixed Sources--Organic Gases. Organic emissions from petroleum marketing, dry cleaning, degreasing, and other organic solvent users are assumed to be uniformly distributed over the highly populated squares between the hours of 6 a.m. and 6 p.m. PST. Surface painting and coating operations emissions are distributed uniformly between 6 a.m. and 6 p.m. PST in proportion to the number of paint bake oven permits in each square. Petroleum production organic emissions are spread uniformly over 24 hours and in proportion to the number of petroleum processing equipment permit units in each square. Incineration, mineral processing plant, power plant and other industrial organic emissions are not considered significant enough to be included.

All Fixed Sources--Carbon Monoxide. The total fixed source carbon monoxide emissions in the modeling area are considered negligible.

C. Model Availability

Although the emission inventory methodology has been thoroughly discussed and the appropriate equations listed, no operational computer code is included in the report.

XXIII SYSTEM DEVELOPMENT CORPORATION

Development of a Simulation Model for Estimating Ground Level Concentrations of Photochemical Pollutants. M. Weisburd, L. G. Wayne, R. Danchick and A. Kokin, Final Report. System Development Corporation, prepared for Environmental Protection Agency, Contract No. CPA 70-151, January, 1971.

A. Author's Abstract

Modeling photochemical air pollution for simulation on the computer must, at the present time, be based on the limited operational and experimental data available. Computer simulation dictates that the gaps and uncertainties which occur in our present understanding of photochemical pollution be dealt with in order to simulate the photochemical system as a functional whole. All modeling, therefore, must involve the making of assumptions and the application of theoretical considerations. Modeling strategies largely differ in the type and amount of theory applied.

The approach taken by the System Development Corporation (SDC) stays relatively close to the state-of-the-art in that (1) while the conveniences of theoretical mechanisms are necessary in some instances, the modeling is largely based on the operational and experimental data available, (2) the first iteration of the concept of the model is based on present understanding, and (3) the basic model is flexibly constructed so that it can be modified, expanded, and refined as new information becomes available.

SDC, accordingly, has taken an approach which emphasizes those mechanisms and functions which through experience and observation, in themselves, and in combination, appear to have the greatest potential for predictive accuracy. These include, in their order of assumed importance: (1) chemical mechanisms; (2) the trajectory (and history) of moving air parcels; and (3) the effect of vertical stability (mixing depth).

The basic assumption taken is that the chemical mechanism largely governs, both quantitatively and qualitatively, the ground level concentrations of primary and secondary contaminants at particular times and locations. This accuracy is dependent upon, and is maximized by the ability to follow in a detailed manner the cumulative build-up of pollution in samples of air as they move across the metropolitan area. The 33-step, 25-species mechanism, and the calculation of trajectories based on a dense network of meteorological stations, contained in the current version of the model, reflect the degree of confidence placed in this approach. The calculation of mixing depth is of similar importance as it affects the concentrations of primary pollutants.

B. Summary

The SDC model is an early version of the REM transformation model, the emissions treatment of which has been previously discussed. It should be noted that an earlier version of the model contained a subroutine to include pollutants from large point sources. However, initial runs of the model with this routine indicated no significant difference in air quality from that obtained using area source emissions alone, although an insufficient number of trajectories were run to conclusively establish the impact of the routine.

1. Sensitivity to Changes in Emission Factors

One sensitivity run consisted of doubling the emission factors for all contaminants. The results were an approximate 20% increase in ozone, no appreciable effect on NO_2, nearly an 11% increase in CO, and a 25% reduction in nitric oxide concentrations. The effect of doubling emission factors must be taken as the doubling of emissions in the immediate vicinity of the trajectory only, as changes in emission factors do not affect the value of background concentrations.

Reduction of the emission factors by one-half decreased ozone concentration at the trajectory terminus by only 1 pphm, CO by approximately 5%, and both oxides of nitrogen by less than half the control values.

The emission factor for nitric oxide alone was increased by 25%, with a negligible effect on concentration.

2. Sensitivity to Changes in Background Contamination

The effect of reducing background contamination was explored in a series of runs using different trajectories. Results confirm that the relative effect differs "substantially" from one location to another.

3. Sensitivity to Changes in the Diurnal Traffic Curve

The diurnal traffic density curve used in the model assumes a peak at 8 a.m. PDT and a constant lower value between 1 p.m. and 6 p.m. PDT. Two runs were made with different trajectories, where the assumed traffic density curve was altered. For one run the curve was shifted so that the morning peak occurred at 7 a.m. PDT, resulting in minimal changes in concentrations from those of the control run. The other case tested utilized a trajectory leading to downtown Los Angeles that was much more directly affected by the morning traffic peak. The curve was shifted by 2 hours, resulting in a 50% reduction in ozone, a one-third reduction in CO, little change in NO_2, and approximately a 100% increase in NO. The effect of change in the curve is highly dependent on trajectory location and time of day.

XXIV TRAVELERS RESEARCH CORPORATION

Sensitivities of Air Quality Prediction to Input Errors and Uncertainties. G. R. Hilst, Proc. of Symp. on Multiple-Source Urban Diffusion Models, Chapel Hill, N.C., APCO Pub. No. AP-86, 1970.

A. Author's Abstract

With the advent of computer-oriented simulation models of the physical and chemical system that produces varying levels of air quality, it is both possible and desirable to assess the model's sensitivities to errors and uncertainties in the input variables. From such analyses, it is possible to derive more explicitly the levels of accuracy that must be observed in the specification of the inputs for source strengths and distributions, wind velocity, horizontal and vertical diffusion rates, and pollutant chemical reactions or physical decay and loss rates, if the air quality predictions derived from these inputs are to remain within useful limits of accuracy and uncertainty.

For the present report, a single case study is utilized to test the sensitivity of the Travelers Research Corporation Regional Model to random and systematic errors in the source-strength input and to systematic errors in the remaining input variables. It has been found that random errors in the source strengths do not produce comparable errors in the air quality prediction. Beyond this, and in order of decreasing sensitivity, the TRC model has been found to be highly sensitive to systematic regional wind-direction errors and moderately sensitive to systematic errors in source-strength estimates, decay or loss rates, and vertical diffusion rates. The model is insensitive to errors in lateral diffusion rates, at least for the multiple-source distribution encountered in Connecticut. These Sensitivities are quantified for the case studied.

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The case used for the sensitivity analyses also provided an opportunity to determine the effect of changes in the input variables on the verification of the model, since observations of SO_2 were available from the verification program. Significant improvements in the TRC model verification, over that obtained from the original, independently chosen, input variables, were found when either the source strengths or the decay or loss rates were adjusted appropriately. **This result suggests the need** for much better understanding of the decay and loss of airborne SO_2.

B. Summary

Using the Travelers Research Center Gaussian plume model, an assessment was made of the model's sensitivity to errors in various input parameters, including misestimates of source strength and positional errors.

1. Source Strength Error

The model was found to be relatively insensitive to large random errors in the specification of source strength. Evidently, among multiple sources random errors tend effectively to cancel each other. Assuming a Gaussian distribution of fractional error in concentration

$$\frac{X_T - X_E}{X_T}$$

where X_T = true value of concentration

X_E = erroneous value of concentration

the range of the fractional error increases by only a factor of 2, while the RMS value of the error in source strength, Q, increases by a factor of 8.

While no systematic error in concentration is introduced by random errors in Q, the standard deviation of concetration error is broadened as random errors in Q increase.

The model was much more sensitive to systematic errors in Q. Since it is prescribed that the concentration, X, is directly proportional to Q, there must be a one-to-one correspondence between systematic errors in Q and errors in X. Thus,

$$\overline{[(X_T - X_E)/X_T]} = \overline{[(Q_T - Q_E)/Q_T]}$$

The standard deviation for systematic error is zero.

3. Positional Error

Mislocation of sources, receptors, etc., automatically invokes errors in all of the input parameters. Therefore, a systematic error in the direction of the general wind field was utilized for the assessment of sensitivity to the compounded errors of position. Noting that the reference values for all input parameters were arbitrarily chosen, results show that mean error is less than or equal to 50% and individual error is greater than 200%. The mean fractional concentration errors are not extreme, but the spread of these errors is.

XXV TRW

Prediction of The Effects of Transportation Controls on Air Quality in Major Metropolitan Areas. Prepared by TRW, Inc., McLean, Virginia, APTD-1363, EPA, Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina, 27711.

A. Author's Abstract

Transportation data in the form of vehicle miles traveled (VMT) by geographic areas have been used as the basis for calculating emission rates and air quality. The methodology involved:

Step 1. Assignment of VMT and speed to elements of a grid network. This required superimposing a rectangular grid network consisting of one mile squares or one kilometer squares over a base map of the metropolitan area and summation of VMT from each of the individual roadways which may fall within one of the small grids to obtain the total VMT for each element or small grid in the grid network. The speed for each grid of the grid network is obtained by averaging the speeds from each element or roadway within the grid for each element of roadway as a proportioning factor. In this manner the many vehicular sources moving within an individual grid can be represented by a single stationary source, which produces the same amount of emissions, equal to the size of the individual grid. This equivalent source is called an area source because the emissions from the grid or area source are now considered as evenly distributed or evenly produced over the entire area of the individual grid.

Step 2. Use of vehicle emission factors to calculate emissions on a per-grid basis.

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Step 3. Conversion of emission rates to pollutant concentration on a per-grid basis by the method of Gifford and Hanna.[1]

Step 4. Application of transportation control strategies to the data base to obtain predicted concentration patterns for each control strategy for the year 1977.

The resulting concentrations are presented graphically as isopleths over a map of the metropolitan area. Pollutants considered were carbon monoxide, hydrocarbons, and oxides of nitrogen, with carbon monoxide being of primary interest.

B. Summary

Transportation data in the form of vehicle miles traveled (VMT) by geographic areas have been used as the basis for calculating emission rates and air quality. The methodology involved:

Step 1. Assignment of VMT and speed to elements of a grid network. This required superimposing a rectangular grid network consisting of one mile squares or one kilometer squares over a base map of the metropolitan area and summation of VMT from each of the individual roadways which may fall within one of the small grids to obtain the total VMT for each element or small grid in the grid network. The speed for each grid of the grid network is obtained by averaging the speeds from each element or roadway within the grid for each time period required, using the VMT along each element of roadway as a proportioning factor. In this manner the many vehicular sources moving within an individual grid can be represented by a single stationary source, which produces the same amount of emissions equal to the size of the individual grid. This equivalent source is called an area source because the emissions from the grid or area source are now considered as evenly distributed or evenly produced over the entire area of the individual grid.

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[1] S. R. Hanna and F. A. Gifford, Jr., "Urban Air Pollution Modelling," Presented at 1970 International Air Pollution Conference of the International Union of Air Pollution Prevention Associations, ATDL Contribution No. 37.

Step 2. Use of vehicle emission factors to calculate emissions on a per-grid basis.

1. Specific Approach

From urban transportation demand models (the traffic assignment portions), VMT and speed data were obtained. Wherever possible, VMT and speed data were obtained by zone. If no zonal information was available, zonal estimates were made. However, the emission levels are actually used as average zonal values and are rough approximations rather than point measures. In addition, the factors used to convert VMT and speed data into emission levels themselves introduced errors which are of at least equal magnitude to those introduced by allocation of link VMT into zones. Most of the VMT and speed information supplied was for a 24-hour average weekday (in some cases peak-hour data were available) and, therefore, had to be adjusted to estimate the eight-hour and one-hour maximum requirements of the project. These estimates were made utilizing daily hourly traffic counts made available by the traffic departments and transportation planning agencies in each of the cities.

Most of the traffic assignment data provided had base years in 1968 and 1969. These same models generally provided projected values for VMT (and very often speeds) for the year 1980 and beyond. Interpolations, therefore, had to be made for the year 1977. In making these interpolations employment, residential, and population data were used whenever available. When these data or growth models were not available, interpolations were generally based on straight line assumptions.

In a number of cities speed information had to be estimated for each of the zones. When this was done, the speeds were based upon link-node data using weighted averages weighting the respective speeds using link volumes as weights. The program input and output are oriented to a rectangular grid network which overlays the city of interest. The results are presented in tabular form as the average concentrations for each element of the grid network. Punched card output was used to produce concentration isopleths or concentration density maps which were overlaid on a map of the metropolitan area to give a visual representation of the spatial distribution of the pollutant of interest.

2. Program Input

Three groups of input data are required: traffic data, meteorological data, and emission factors for each pollutant.

Traffic Flow Data. The resulting grid network of VMT and speed from above provide the basic traffic flow data required for emission calculations.

To correspond with the time periods specified by the National Ambient Air Quality Standards, peak 1-hour and peak 8-hour VMT are required. For comparison with the ambient air quality standards for hydrocarbons and nitrogen dioxide, a Larsen transformation was used to convert estimates to 3-hour and annual averages, respectively. When these data were not available, they were estimated as percentages of the 24-hour VMT by using traffic count information at various stations within the area. The program applied this percentage whenever necessary to obtain the appropriate data format. Particular streets may vary significantly from the mean values obtained by this procedure; however, the allocation of VMT to grids as described above tends to minimize the effect of individual streets on the predicted concentrations values for the individual grid.

Traffic speed data on a per-grid basis are required as an adjustment to the average vehicle emission factors. Carbon monoxide and hydrocarbon emissions decrease with increasing average vehicle speed; therefore, the emission factors must be adjusted to be more realistic. EPA has published emission factors curves as a function of average vehicle speed for carbon monoxide and hydrocarbons. These curves are incorporated in the program.

The modal split of VMT must be considered, i.e., what is the proportion of cars, buses, and trucks comprising the total VMT. Data on the modal split are not typically available on a detailed basis; therefore, this factor is most readily accounted for in the formulation of area emission factors as discussed below.

Emission Factors. EPA has developed a computer program to produce emission factors for the entire vehicle population for a given metropolitan area for any calendar year from 1960 to 1990 for which vehicle age-type distribution data are available. Emission factors are subject to revision as required by changes in vehicles, control devices, "representative" driving cycles, and measurement techniques.

3. Outputs

1. Annual emissions (tons/year) for each grid and total emissions for a grid network.
2. Emission rates ($mg/m^2/sec$) for each grid.
3. Total 8-hour and 1-hour emissions for each grid.

4. Resolutions

Generally, the data available for each city did not permit classification into fine-grained geographic areas (e.g., the eight rings used for Washington, D.C.). Since the impact of flow controls was based on general experience and judgment, for the purposes of project analysis, the respective cities (except Washington, D.C.) were divided into three broad geographic areas: (1) the CBD or core, (2) an area surrounding the core but still within the political boundaries of the city, and (3) the remaining area outside the boundaries of the city. This three-way division allowed relatively easy division of zones while still permitting our analysis to be somewhat more fine grained than would otherwise be possible.

EMISSION MODELS CHECKLIST

Input Data Requirements

	Within Program	User Supplies	From AP-42	Proxies/Comments
Vehicle Emission Factors				
-By model year	x	x		Uses vehicle mix for year of interest in study
-By size class	x	x		
-By power plant	x	x		
-Deterioration factor	x	x		
Vehicle Operating Modes				
-Hot/cold start		NP		
-Route average		x		Speed and distance
-Link average		NP		
-Mode-by-mode		NP	NP	
Traffic Features				
-Vehicle mix		NP		
-Engine operating time		NP	NP	
-Vehicle miles traveled		x	NP	
-Fuel consumed		NP	NP	
Spatial Distribution				
-Links		NP	NP	
-Grinds		x	NP	
-Area		x	NP	

NP = No provision

Output Available

Pollutants	
-CO	Yes
-HC	Yes
-NO_x	Yes
-Particulates	No

Availability of Program Documentation

	Yes	No
Included in report		x
Referenced in report	x[*]	
Language	NP	
Equipment	NP	

Validation/calibration: Compared with Washington, D.C., camp data; CO CO data show best agreement

Time resolution: 1 hour; 8 hour

Spatial resolution: 1 mile or 1 kilometer square

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[*] Uses EPA computer program for emission factors for entire vehicle population for a given metropolitan area for years 1960 to 1990.

XXVI UNIVERSITY OF ALASKA

Ice Fog: Low Temperature Air Pollution. Prepared by Carl S. Benson, Geophysical Institute, University of Alaska, UAG R-173, November, 1965.

A. Author's Abstract

Stable pressure systems over interior Alaska sometimes produce prolonged extreme (below -40° C) cold spells at the surface. The rate of radiative cooling of the air is enhanced by suspended ice crystals, which are themselves a result of the initial cooling.

Radiation fogs formed during the onset of cold spells are generally of short duration because the air soon becomes desiccated. These fogs consist of supercooled water droplets until the air temperature goes below the "spontaneous freezing point" for water droplets (about -40° C); the fog then becomes an ice crystal fog, or simply "ice fog." During the cooling cycle, water is gradually condensed out of the air until the droplets freeze. At this point there is a sharp, discontinuous decrease in the saturation vapor pressure of the air because it must be reckoned over ice rather than over water. The polluted air over Fairbanks allows droplets to begin freezing at the relatively high temperature of -35° C. Between -35 and -40° C the amount of water vapor condensed by freezing of supercooled water droplets is three to five times greater than the amount condensed by 1° C of cooling at these temperatures. This results in rapid and widespread formation of ice fog, which persists in the Fairbanks area as long as the cold spell lasts. The persistence of Fairbanks ice fog depends on a continual source of moisture (4.1×10^6 Kg H_2O per day) from human activities within the fog.

Ice fog crystals are an order of magnitude smaller than diamond dust, or cirrus cloud crystals, which in turn are an order of magnitude smaller than common snow crystals (0.01, 0.1 and 1 to 5 mm respectively). The differences in size are shown to result from differences in cooling rates over five orders of magnitude. Most of the ice fog crystals have settling rates which are slower than the upward velocity of air over the city center. The upward air movement is caused by convection cells driven by the 6° C heat island over Fairbanks. This causes a reduced precipitation rate, which permits the density of ice fog in the city center to be three times greater than that in the outlying areas.

The inversions that occur over Fairbanks during cold spells begin at ground level and are among the strongest and most persistent in the world. They are three times stronger than those in the inversion layer over Los Angeles. Thus, the low-lying air over Fairbanks stagnates and becomes effectively decoupled from the atmosphere above, permitting high concentrations of all pollutants. The combustion of fuel oil, gasoline, and coal provides daily inputs of 4.1×10^6 kg CO_2; 8.6×10^3 kg SO_2; and 60, 46 and 20 kg of Pb, Br and Cl respectively, into a lens-like layer of air resting on the surface with a total volume less than 3×10^9 m^3. The air pollution over Fairbanks during cold spells couldn't be worse, because the mechanisms for cleaning the air are virtually eliminated while all activities that pollute the air are increased.

B. Summary

Aqueous emissions are an important pollutant in Fairbanks, Alaska, in cold weather, when the capability of the air to hold water in solution is reduced. The Geophysical Institute, University of Alaska, estimates aqueous and CO_2 emissions from combustion, power plant cooling ponds, and miscellaneous sources, such as sewage treatment plants, mine tunnels, people and animals breathing.

1. Combustion Emissions

Complete combustion of the representative molecular species is assumed, with average molecular weight ratios of 1.38 (H_2O/fuel) and 3.10 (CO_2/fuel) for gasoline and 1.33 (H_2O/fuel) and 3.13 (CO_2/fuel) for fuel oil. For coal, the calculation of these ratios is more complex because the water contained in coal is exhausted directly to the atmosphere during combustion. It is assumed that 20 percent by weight of the coal is water. Total molecular weight ratios for coal are 0.68 (H_2O/fuel) and 2.37 (CO_2/fuel).

The above ratios are applied to the quantities of each fuel type burned to give monthly and daily emissions of H_2O and CO_2.

2. Power Plant Cooling Emissions

Given the water flow rate to and from the cooling pond and the net temperature change of water, the required heat loss may be calculated. This heat loss is accomplished by three processes: (1) evaporation to the atmosphere; (2) radiation to the sky; and (3) conduction through the bottom of the pond.

Assuming an extreme winter vertical temperature gradient in the pond, no convection in the water, and the condition of all heat conducted downward being conducted away through the soil below, the calculated vertical heat flux from conduction for a large plant at Fort Wainwright, Alaska, is less than 0.1 percent of the total required flux. Therefore, conduction can be neglected.

Radiative cooling is maximized using

$$Q = 0.105 + 0.0018\ T$$

and multiplying Q by the area of the pond. A temperature T over the open water surface must be assumed. The value of maximum radiative heat flux at the plant cited above is slightly over 5 percent of the total flux and is negligible when ice fog forms over the pond. Therefore, during ice fog conditions, the evaporative heat loss approaches the value of the total heat loss.

To estimate the amount of water introduced into the atmosphere from power plant cooling waters, each plant must be analyzed separately in a manner similar to that described for the Fort Wainwright plant.

3. Miscellaneous Emissions

Aqueous emissions from miscellaneous sources such as sewage treatment plants are treated individually by calculating heat loss from the warm water discharge flow rate, the amount of open water area, the amount of heat dissipated by mixing with river water, and so forth. For tunnels, the moisture flow rate through the fans (and therefore the emission rate from tunnels) are estimated using the air flow rate past the fans and the relative humidity and temperature of the air. Another important source of aqueous emissions in very cold climates is the breathing of people and animals. Saturated air is exhaled at 35° C. This exhalation process together with respiration rates and the populations of each sex and species gives the amount of water vapor released to the environment. It has been shown that the loss of water vapor through perspiration exceeds the loss from respiration; therefore, the moisture output from breathing can be doubled to give a combined perspiration and respiration loss.

Other miscellaneous sources include moist air discharge from laundries and air leaks from buildings and houses.

XXVII UNIVERSITY OF CALIFORNIA AT DAVIS

The Impact of Highways on Air Quality. L. O. Myrup, unpublished report, August, 1972.

A. Author's Abstract

None given.

B. Summary

Carbon monoxide emissions for Sacramento, California, input to the pollution transport and diffusion model developed at the University of California at Davis are distributed into 1.7 mi^2 areas. Total emissions for each area are formulated by first measuring the total miles of residential streets, arteries, and highways in each area. The average traffic volumes for each of the three types of streets are obtained, and car-mile factors computed. Vehicle emission factors at appropriate vehicle speeds are then applied, yielding the total amount of pollutant for each kind of street, and after summation, the total emissions for the grid square in question.

C. Model Availability

No computer program for the emission inventory methodology presented is available.

XXVIII U.S. WEATHER BUREAU

A Simple Diffusion Model for Calculating Point Concentrations from Multiple Sources. J. F. Clarke, Journal of the Air Pollution Control Association, September, 1964.

A. Author's Abstract

None given.

B. Summary

The application of a method designed by Hagan, et al. (1964)[1] resulted in the source inventory for the city of Cincinnati used in Clarke's calculations. Two source categories for sulfur dioxide and nitrogen oxides are presumed: (1) combustion sources, which include space and process heating, power generation, transportation, and waste incineration sources; and (2) industrial process losses, which include only the losses from processes, not from combustion. Emissions are allocated on the basis of unit-area emission rates for each of 19 areas suggested by population density maps and modified subjectively to more clearly define commercial and industrial areas.

Among the assumptions made in apportioning emissions are that the amount of fuel used for space heating is directly proportional to the degree day value, and that this fuel is used only during days registering a degree day value. It is assumed that industrial and commercial sources that use fuel for power and waste incineration and process heat operate at a uniform daily rate. Fuel used for transportation is taken as constant for days without a degree day value and inversely proportional

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[1] J. E. Hagan, III and G. A. Jutze, "A Rapid Technique for an Air Pollution Emissions Survey," Public Health Service Manuscript (1964).

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to that value when one is registered. This assumption is based on seasonal variations of gasoline sales.

The industrial process losses used are engineering estimates derived from knowledge of the characteristics of the individual processes, as sufficient quantitative data was not available.

One power plant was thought significant enough to be included as a point source. The plant does not operate at a uniform daily rate, and fuel usage is not a simple function of season or time of day, since the output of the plant is used to both heat and cool, according to season. Since operational data from the plant were not readily available and the precision of the general inventory did not seem to warrant the effort required to calculate otherwise, emissions from this plant were taken as invariant in time.

C. Model Availability

A computer code for the emissions treatment used for Cincinnati is not referenced in the paper.